STEEL HELIX

A Gunsmith Machinist's Answer to the Question of the Rifled Barrel

Charles J. Moore

STEEL HELIX

A Gunsmith Machinist's Answer to the Question of the Rifled Barrel

Charles J. Moore

Copyright © 2012 Charles J. Moore

2nd Edition Published by The Appalachian Rifle Shop.
Printed in the USA.

Library of Congress Registration Number: TXU001830409
ISBN: 978-0-615-86282-8

All rights reserved. No part of this book may be reproduced or transmitted in any form or by any means, electronic or mechanical including photocopying, recording or by any information storage and retrieval system, without the written permission of the Author.

This book is designed to provide the reader with information on the subject matter covered. It is not designed to be a complete guide to gunsmithing or the sole authoritative work on the subject. It is sold with the understanding that the Author is not engaged in giving professional or technical advice.

The information in this book is true and complete to the best of the Author's knowledge. All recommendations are made without any guarantee on the part of the Author, who also disclaims any liability incurred in connection with the use of this data or specific details.

CONTENTS

Introduction 4

Chapter 1: The Barrel Maker's Machine Shop 8

Chapter 2: Methods of Rifling a Barrel 19

Chapter 3: Indexing the Twist Rate of Cut-Rifling 30

Chapter 4: The 3-in-1 Barrel Machine 40

Chapter 5: The High-Pressure Oil System 66

Chapter 6: Barrel Tooling 78

Chapter 7: Machining Operations 119

Chapter 8: Understanding Barrel Steel 147

Chapter 9: Proof-Firing 171

Bibliography 190

Introduction

Ever since I first pondered how one might go about the task of creating a rifle barrel when I was just a lad, it has always seemed kind of like building a ship in a bottle. Just exactly how do you get tools in there to do some work? And how do you see what you're doing? At least when you build a ship in a bottle, the interior of the workspace isn't a dark and mysterious unknown. Making the hole wasn't the part that puzzled me. I knew what drills were and how to use them, although I must admit that I couldn't imagine drilling a hole *that* deep. But the rifling was a different sort of animal and I had absolutely no idea how you could cut grooves inside such a small hole, much less make them wrap and curl around the bore as they progressed forward. In those days, my ignorance and befuddlement concerning machine shop practice were so complete that I had no choice but to chalk the whole thing up to some sort of black voodoo magic and get on with my life as best I could.

As the years passed, I didn't give the matter too much thought because there really wasn't any pressing need driving me to learn the secrets of the barrel maker's art. And let's face it, despite the fact that rifled barrels have been in production for more than two centuries, there is precious little *useful* information that has been written down on the subject. Over time, I became a fair to middling deer hunter. By the time I had reached my mid-twenties, it was a foregone conclusion that I was going to put as much venison in the freezer each fall as I wanted. Success breeds knowledge and I began to form some very definite opinions concerning what did, and didn't, work well in the field. One of the strongest opinions that I formed during those years was the conviction that 50 caliber muzzleloaders aren't always the best medicine for big game; they are seriously lacking in penetration on angled shots and the blood trails their wounds induce aren't always reliable. It's not that the 50 calibers aren't enough gun. They are, but just barely. And I never learned how to settle for just barely. So I began a search for a bigger, better charcoal-burner.

As many of you who have engaged in the same search will already know, my search was rather frustrating and bore little fruit. But then, when I was just about ready to give up hope, the Kodiak Express 12-bore (72 caliber) double-barrel from Davide Pedersoli came on the scene. It was love at first sight and I simply *had* to have one of those rifles, so I bought one. The rifle, while certainly not a tack-driver, proved to be accurate enough for typical woods-range shots out to about 100 yards. And with a nearly three-quarter inch, 550 grain round ball rumbling along at over 1,500 fps, the "just barely" character of muzzleloader penetration and blood trails changed abruptly to "more than adequate". I like more than adequate. As the seasons came and went, deer and hogs fell at a steady rate whenever and wherever the 12-bore spoke, because it spoke with unquestionable authority. But, as satisfactorily as the Kodiak rifle performed for me in the field, I couldn't help but yearn for a little more accuracy out there where the dandelions grow tall. Like I said, I never learned how to settle for just barely. I also realized that there are some hunts that would never be in the Kodiak's future simply because there are some states that do not allow the use of double-barreled muzzleloaders for the hunting of big game. What if I wanted to hunt elk in Colorado during muzzleloader season? I certainly couldn't use a 50 caliber for elk now that I had grown accustomed to the power and penetration of a 12-bore when hunting deer. That was

absolutely unthinkable. So I began another search, this time for a *single-barreled* large-bore. I tried a few large-bores from custom makers, but those rifles with their Forsythe-rifling couldn't even *match* the accuracy of the Kodiak, much less exceed it. I even contacted Davide Pedersoli in Italy to see if they could be induced to build a single-barreled 12-bore rifle (at that time, they made only smooth-bores in single-barreled configuration), but they would not. As my frustration grew, a long-neglected but deep-seated question slowly began to work its way back to the surface: how are rifle barrels made? You see, my quest (obsession?) for an accurate, powerful, single-barreled, large-bore muzzleloader was inexorably leading towards the only possible conclusion. I was going to have to build the thing myself.

This is the Pedersoli Kodiak that indirectly inspired me to become a barrel maker. On this particular day, the rifle put a 550 grain round ball right between this boar's eyes as he faced me down at a range of 15 yards. I don't know if he was planning to fight or flee, but the 12-bore decided the issue for him.

After deciding that I was going to fabricate my own muzzleloader barrels, I began yet another search. This time I was looking for any tidbit of information I could find that pertained to the crafting of rifle barrels. At first glance, it seemed that there was a bountiful supply of information on the subject. But as I began to dig deeper and really examine the available nuggets of wisdom, I found that much of what had been written on the subject was rather vague and not too helpful for readers like me who wanted to actually *make* barrels, not just learn about the process in general. Eventually, I dug up

enough information from several different sources that I was able to build my own machine, fabricate my own tools, and finally make my own barrels. Since then, I have learned far more through hands-on experience and practical application. But I haven't forgotten how difficult it was to scrounge together enough information to get the ball rolling. This volume of work is my contribution to the shooting world and it is intended to fill the glaring void in our collective, written knowledge on the subject of rifled barrels. This is the book that I wish had been available when I was taking my first few tentative steps down this road.

While this book does contain everything I know (well, almost everything– a guy's got to have *some* secrets) about the specific processes involved in fabricating rifle barrels from solid bars of steel, it is not a work that can stand alone. In addition to the information found here, you will need to know several volumes worth of information about general machine shop practice if you intend to build your own machine and make rifle barrels yourself. This type of general machining know-how is beyond the scope of this book. Fortunately, and in sharp contrast to the store of published information that deals specifically with rifle barrels, there is no shortage of information available concerning the proper use of machine tools. I have listed several very useful references in the bibliography. In combination with this volume, these references will provide the rest of the information needed to become a full-fledged barrel maker. The bibliography also lists other sources of information pertaining specifically to making rifle barrels. If you intend to make barrels yourself, I strongly recommend that you also consult these other sources. There are some alternate techniques described in them that either didn't work so well for me or weren't applicable to what I was trying to do, but you may find the techniques very useful in your own endeavors.

Note carefully that I did not say that you will also need to spend years in apprenticeship to an established barrel maker in order to learn the trade. The perception that the trade can only be learned through long apprenticeship is very old and very romantic, but it is simply outdated in the contemporary age of information. I, myself, have never spent a single day under the tutelage of another barrel maker. I learned everything through a combination of reading and trial-and-error. Having said that, if you do happen to know a barrel maker with whom you could learn the ropes, by all means, jump at the opportunity! Yes, you can learn everything that he knows on your own... eventually. But learning from his experience will make the trip a whole lot shorter and the learning curve a lot less steep.

For those of you who have no intention of building and using your own machine to drill, ream and rifle barrels, this volume will nonetheless provide you with a very intimate knowledge of the process. And knowledge for its own sake is not a bad thing. I hope that, by the time you have turned the last page, you will have a much deeper appreciation for what those of us who make barrels have to go through to put those sleek, shiny rifles in your hands. A riflesmith who truly takes pride in his work could ask for no greater gift than a customer who truly appreciates the finished product. This type of understanding creates a far deeper camaraderie between craftsman and sportsman than can be attained through a mere monetary exchange and the lives of both are enriched by the shared experience. I can't speak for every riflesmith, but, when my customers send me pictures of their hunts, I feel far more pride in their harvest of big game animals with barrels that I made for them than I have ever felt about the harvest of critters by my own

hand. There's just something about seeing one of my creations out there on its own doing good deeds for someone else. It makes me feel as if I've accomplished something that was truly worth the time and effort. It is my sincere hope that this book will provide you with the knowledge and inspiration to take the time and expend the effort to do something that is truly worthwhile for yourself.

Charlie Moore
Oakland, MD
September, 2012

CHAPTER 1: The Barrel Maker's Machine Shop

Any barrel maker, especially one who is building his own barrel machine, will need to have, or at least have access to, a basic machine shop. Basic is the key word. You will not need several large CNC machines that each cost as much as a modest home. A few basic machines, coupled with sound manual machining practices, will fit the bill quite nicely.

The subject of machining practice and technique is beyond the scope of this book and, in fact, requires an entire volume of written work to cover thoroughly. The bibliography lists several very useful sources of information on the topic of machining practices. Unless you have been operating machine tools since you were knee-high to the proverbial grasshopper, you should purchase a few of these references (or others like them) if you plan to build your own machine to fabricate your own barrels. They will provide you with the machining information not covered in this body of work. However, I would be remiss if I didn't mention a few things about basic safety and competence in the machine shop before discussing the types of equipment your barrel shop will require.

Basic Rules

Always roll up your sleeves and remove watches, rings, necklaces, etc. to avoid getting tangled in the machine or workpiece. I once read an account of an engineer who was wearing a necktie while running a lathe. He would have been sucked into the machine when the lathe dog snagged his fashionable accessory if not for the extremely quick reaction of a coworker who turned the machine off. I don't have a clue what kind of thought process led him to believe that wearing a tie in a machine shop was proper and necessary, but it was a decidedly poor idea. Gloves are off limits too. Cold fingers are far easier to remedy than broken or severed fingers. This business about keeping garments and accoutrements out of the machine is an absolutely inviolate rule of machining. Seriously, when a machine snatches you up, it *will* have its way with you. If you've ever had a hand-held, ½" electric drill wind your arms around each other like a Twizzler when the drill bit got caught on a thick chip, you know exactly what I'm talking about. Unless treated with respect, machine tools will do far more damage to the operator than a hand-held drill ever could.

Always wear safety glasses. Even when a machine is running at low rpm's, the chips being cut are under considerable pressure and can travel quite some distance after releasing from the workpiece. I've never had a steel chip in my eye and I intend to keep it that way.

Before switching gears or belts to change thread pitch or motor rpm range, make sure that the machine is unplugged. Not just switched off, but completely disconnected from the power source. Your fingers will thank you for taking the time to do this when they're still attached to your hand at the end of the day.

When filing a workpiece in the lathe, always point the tang of the file away from your hand, forearm and midsection. You do not want any part of your body in harm's way when (not if) the workpiece or chuck catches the file and thrusts it violently in the direction of rotation. Putting handles on your files will alleviate this concern and we all know it, but, seriously, how many of us actually have handles on *all* of our files? And how many of us will walk all the way across the shop to get a file with a handle when

there's a perfectly good file with a bare tang lying right next to the lathe? Files with bare tangs are completely safe to use with a lathe as long as you treat them like loaded guns. *Never* point a naked tang toward anything that you don't intend to punch a hole through.

Focus on the task at hand. This is easier said than done, especially near the end of the day. At times, machining can be very tedious and it's a sure bet that your mind will begin to wander during a long, monotonous series of cuts. If you're thinking about bills, cars, football, hunting, fishing, blondes, brunettes or redheads, do not even attempt to operate a machine tool. At best, you'll make a cut in the wrong place and ruin the workpiece. And, of course, you won't ruin it on the first cut. You will ruin it after investing hours, or even days, machining it to the state of completion it was in when you made the faulty cut. Even worse, if you try to push your luck and cut steel when you're not completely focused on the task, you may injure yourself simply because you forgot one of the other safety rules. I've never injured myself with a machine tool, but I cringe every time I think of all the wasted hours spent on workpieces that I've ruined while trying to make "one more cut" before taking a break or calling it a day. Trust me, you will be much further ahead and waste much less time in the long run if you shut down and walk away from the machine when your mind begins to drift.

Do a dry run under manual feed with the machine power off before completing a setup and starting a cut. This ensures that the setup will allow enough travel to complete the cut without running the cutting tool into the machine (chuck, vise, etc.). This simple procedure will save you the frustration of going through a complicated setup only to have to tear it down and start over because you can't complete the cut. It will also ensure that you never damage your machine because of absentminded carelessness.

Ensure that your setup and cutting tool are solidly fixed and absolutely rigid before beginning a cut. The process of cutting steel looks smooth and easy with a rigid setup. But if you attempt a cut with a shaky setup or loose cutting tool, you will quickly realize just how much pressure is involved in shaping steel to your will. Machining operations get very scary in a big hurry when sharp steel objects that are supposed to be fixed in position start flying about in a willy-nilly fashion.

As I mentioned above, there is far more to being a competent machinist than I've covered here. But these suggestions do cover, in my humble opinion, the most important "always do" and "never do" rules of operating machine tools. Now let's have a look at the type of machining equipment required to run a rifle barrel shop.

The Lathe

There are a few key components of the barrel machine itself that must be made on the lathe. However, any lathe that is capable of machining rifle barrels will be fully capable of making these few components of the barrel machine. So, the requirements for your lathe will be based on the type and, more importantly, length of barrels you intend to make. The only piece of equipment more important to the barrel maker than the lathe is the barrel machine itself. Turning operations must be made on the barrel blank both before and after the drilling, reaming and rifling operations. In fact, *all* operations on the barrel that don't directly involve machining the bore are done on the lathe. The only exception to this statement is a barrel profile that is either octagon or fluted. A milling machine is used to cut these profiles. For all other operations on a rifled barrel blank, the lathe is king.

A lathe used for making rifle barrels must, first and foremost, have a bed long enough to accommodate the longest barrel you intend to make plus a few extra inches. Those extra inches will allow you to cut off an inch or so of the barrel at each end after the rifling operation. This is a necessary step because the grooves produced by cut-rifling are typically less than perfect at the very ends of the barrel because the cutting tool is not fully supported as it enters and leaves the bore. For typical finished rifle barrel lengths of 24 to 26", a lathe with a minimum of 30" between centers will be required and 36" will give you much more breathing room. A bed length shorter than this will restrict you to making short carbine and pistol barrels.

If you feel it is necessary or desirable to be able to slide barrel blanks through the bore of your lathe's spindle, then you will need to make sure that the bore is large enough to accommodate the barrel profile. One possible reason for a setup like this will be discussed below in the Lathe Tooling section. The standard size of round bar used for barrel blanks is 1¼" in diameter. If you want to make a heavy target barrel that's nearly full diameter, your lathe spindle must have a minimum bore measurement of 1⅜" to allow the passage of the barrel blank with enough room left over to center the blank in the spindle. A smaller spindle bore size will require a smaller barrel profile. This may sound like a minor consideration and, for most calibers and barrel profiles, it is. However, I make only large-bore muzzleloader barrels (.58 and larger) and, unfortunately, my spindle's bore measures only 1⅛". So, for anything bigger than a 58 caliber, sliding the barrel through my spindle is out of the question because the blank diameter required is too large. I can work around this minor handicap, but I wish I had given some thought to the spindle bore size of my lathe before I bought it– I may have gotten a different model.

For some operations, it is very nice to be able to run the lathe in reverse and make cuts on the back side of the workpiece. This is only possible with a lathe equipped with a cam-lock spindle. If the spindle of your lathe is threaded, running the lathe in reverse will cause the chuck or faceplate to unscrew itself during the cut. A heavy chuck dropping onto the ways of the machine is a *very* bad thing. A backward setup like this allows for better visibility and access to the compound rest for some cuts. I typically use this setup for cutting tapers on small parts and tooling by using the manual feed of the compound rest. Some machinists run their lathes in reverse when cutting internal threads so that they can see the threads being cut. If you cut internal threads this way, be sure to reverse the direction of feed as well as spindle direction and cut the threads outward from the internal shoulder or your threads will be cut with a left-hand pitch instead of right-hand.

The lathe should have incrementally variable speed capability. Speeds ranging from 120 rpm up to about 1,500 rpm will be sufficient for working with the diameters and alloys of steel required to build the barrel machine and tooling. Top speeds up to 3,000 rpm can be useful for turning some of the smaller diameter components of the barrel tooling. Higher speeds will also come in handy if you plan to machine workpieces made from aluminum or brass for other projects.

Barrel work does not take much horsepower. A motor with a rating of 1.5 hp will be sufficient and this amount of power is available on lathes that can be used with a normal 110 v, 20 A household electrical circuit. A motor with a power rating above 1.5 hp will likely require a 220 v circuit. Speaking of power, the barrel maker's lathe should certainly have power feed for the x-axis. Power feed for the y-axis is nice, but is not absolutely essential. The barrel maker's lathe should also have a quick-change gear box

for adjusting feed rate and thread pitch. Most (if not all) modern lathes have this feature, but some older models will require the machinist to manually change gears for different feed rates and thread pitches.

Lathe Tooling

The standard tooling for lathe work includes a compound rest, universal three-jaw chuck, face plate, lathe dogs of various sizes and centers for both the headstock and tailstock. Building a barrel machine and making barrels will require the following accessories in addition to this standard tooling package.

Independent Four-Jaw Chuck

The standard universal three-jaw chuck works well for many chores on the lathe, but lacks the accuracy necessary for making the barrel machine's tooling. Nor is it accurate enough to be used for delicate operations like chambering a barrel or crowning a muzzle. An independent four-jaw chuck will allow the workpiece to be precisely aligned on the centerline of the lathe spindle. More importantly, when multiple operations are required on a workpiece, it can be removed from the chuck and re-centered to the exact same standard of accuracy and concentricity as many times as necessary. With a three-jaw chuck, the workpiece must be completely finished before it can be removed from the chuck because there is absolutely no chance that it will run true if re-chucked after being removed for other operations. The four-jaw chuck can also be used to center, drill and bore square workpieces. This is a task that a three-jaw chuck can't manage under any circumstance. Yes, independent four-jaw chucks are a bit pricey, but the absolute accuracy and flexibility they provide makes them well worth the investment.

Steady Rest

A steady rest will be required to make the spindle of the barrel machine as well as much of the machine's tooling. It is also a necessity for profiling round barrels and may be used in place of an outboard cat-head (discussed below) for chambering and threading barrels as well as crowning muzzles. A follow rest may be needed to turn the bed bars of the barrel machine to size but is not necessary for barrel work.

Tailstock Drill Chuck with Extension Socket

The tailstock drill chuck is one item of tooling that is not used at all for making barrels, but will be absolutely essential for the fabrication of some of the components and tooling of the barrel machine. The chuck will need to be able to accept drill shanks from ⅛-½" in diameter. An extension socket will be necessary to reach over the lathe carriage in some tight setups involving the steady rest.

Boring Bars

There are a few key components of the barrel machine and its tooling that will require accurately bored holes. Standard twist drills will not suffice for these items. A boring bar with indexable carbide insert for holes ½" and larger will suffice for most boring operations. Depending on what caliber you choose to make your barrels, you may also require high-speed steel boring bars for smaller diameter holes. Razor sharp, high-speed steel bars for cutting internal threads may be required as well, depending on the

type of barrels you intend to make. For example, I use these to cut perfectly concentric breech plug threads in muzzleloader barrels.

Outboard Cat-Head

I have no idea if "outboard cat-head" is the correct name for this particular gizmo, but I don't know what else to call it. So, for the purposes of this book, outboard cat-head it is! The outboard cat-head is nothing more than an outboard extension of the lathe's headstock spindle with four bolts through it in a radial pattern. The idea is to slide a barrel through the lathe spindle and use the bolts of the cat-head, in conjunction with tight fitting brass mandrels in both ends of the barrel's bore, to precisely center a rifle's bore between the four-jaw chuck and the outboard cat-head. Dial indicators are used on the mandrels while adjustments are made to the chuck jaws and cat-head bolts to accomplish the centering operation. The barrel can then be threaded and chambered, or crowned, with absolute certainty that the operations are being conducted in perfect concentricity with the bore. In effect, the outboard cat-head is basically an outboard independent four-jaw chuck. Some gunsmiths prefer this method, but I use the four-jaw chuck and steady rest to achieve the same effect. I can't use an outboard cat-head because, as mentioned earlier, my lathe spindle's bore is too small to accept the large-bore muzzleloader barrels that I make. The only advantage I can see in using the cat-head (and this is no minor advantage) is the fact that *both* ends of the bore are accessible to the dial indicators simultaneously. When using the chuck and steady rest method, the end of the barrel that will be in the chuck must have an exterior surface that is perfectly concentric with the bore because that end of the bore is hidden inside the lathe spindle and the indicator must ride on the exterior surface of the barrel. An additional operation (with an additional setup) is required to ensure that this perfect concentricity is achieved.

Grizzly Industrial offers a gunsmith's lathe that has the cat-head already built into the spindle. If your lathe is from another manufacturer, you'll probably have to fabricate your own if you want to use this method. If you're lucky, there will be threads exposed beyond the jam nuts that hold your spindle in place. If so, thread the cat-head on and go to work. If not, the cat-head will need to be designed to replace one of the jam nuts. Due to the widely differing dimensions and construction of lathes from different manufacturers, this is as far down this road as I'm going to go. You and your cat-head are on your own from here.

The Mill

The complete barrel shop should include a mill, either vertical or horizontal. But in truth, you can get by without a mill *if* you use commercially available tooling for the barrel machine and you don't want to make barrels with an octagon or fluted profile. The barrel machine can be built without a mill by using the lathe with four-jaw chuck or faceplate and clamps to hold workpieces for drilling and boring; however, setups will be more time consuming and workpieces will likely be less accurately located than if a mill was used for the same task.

For the milled barrel profiles (octagon and fluted), a horizontal mill with enough travel to machine the entire length of the barrel in one setup is ideal. However, for construction of the barrel machine and fabrication of the barrel tooling, I prefer a vertical mill. The vertical mill is preferable because, in addition to milling, it can also be used to

drill and bore accurately located holes. I will not get into the tooling and fixtures required to accurately profile barrels with a horizontal mill; that is a subject for another book.

As with the lathe, the mill should have incrementally variable speed capability. Speeds ranging from 200 rpm up to about 3,000 rpm will be sufficient for milling with high-speed steel end mills from 1/16-1" in diameter with the alloys of steel required to build the barrel machine and tooling.

The vertical mill should have power feed for both the x & y-axis, but power feed is not absolutely essential. Some machinists actually prefer to use manual feed for milling, at least on the first pass, to gauge the amount of pressure being applied to the cutting tool and setup. This is an especially good idea with heavy cuts or setups that can't be made especially robust due to workpiece shape. If equipped with power feed, the mill should also have a quick-change gear box for adjusting feed rate. As with the lathe, a horsepower rating of 1.5 will be sufficient for the barrel maker's mill. Knee/spindle travel of the mill should not be an issue. Any mill with a 1.5 hp rating should have all the travel required for fabricating the components of a barrel machine.

Vertical Mill Tooling

Standard tooling for vertical mills usually consists of an end mill holder for small end mills and a machine vise that can be set at angles ranging from 0-90° to the table. The following additional tools will be required to build the barrel machine and fabricate the tooling for it.

Large End Mills & Holders/Collets

Obtaining the tooling required to use the largest end mills that your machine can handle will save you time and improve the finish of wide milling cuts. These tools are relatively inexpensive pieces of equipment, so the time savings will almost always be worth the modest monetary expenditure. For example, if your mill can handle tools up to 1" in diameter, then you should buy end mills of all sizes from 1/16" to 1" and the holders/collets to handle them. This will save you time and frustration in the long run, but it's not absolutely necessary. A 1" milled slot *can* be made with a ½" end mill, but it will take more than twice as much time to do so. If you're going to use undersized end mills in this fashion, choose the end mill size that is *equal to or just over* one half the desired width of the cut. For example, if a ¾" end mill is used to make a 1" slot, the second cut will only be taking ¼" of material. This causes the mill's cutting edges to enter or leave the workpiece (depending on which direction the work was advanced for the second cut) under a high chip load and this, in turn, causes lots of vibration and tool chatter. It's much better to ensure that the cutting edges enter and leave the workpiece with a low chip load by using a ½" end mill if a 1" end mill is not available.

Drill Chuck

As with the lathe's tailstock drill chuck, the mill's drill chuck will need to handle drill bits with shanks from ⅛-½" in diameter. One piece of advice for drilling *straight* holes without breaking bits– use moderate cutting pressure with lots of cutting oil and back the drill all the way out of the work to clear *all* of the chips from the flutes often. Ignore this I've-been-there-and-done-that advice at your own peril.

Boring Head & Bars

A boring head for your mill will allow precise location and machining of holes in square or odd-shaped workpieces by using the graduated dials of the machine's table. The boring head should be of the adjustable type with a dial graduated in .001" increments. A 2" boring head with a standard nine-piece set of carbide tipped boring bars of various lengths will suffice for building the barrel machine.

Fly Cutters

Fly cutters are not necessary for the fabrication of the barrel machine unless you are shooting for the smoothest finish possible on the machine's components. For those of you who choose to build a barrel machine mostly for the sake of building the machine itself, you may want to consider obtaining a set of fly cutters to make every component perfectly square and smooth. For those who, like me, consider the barrel machine a means to the end of creating barrels, fly cutters certainly aren't required. However, I do have another use for fly cutters. I use them to machine perfectly square and smooth blanks for bullet molds. If you're interested in making your own bullet molds, the same techniques I will show you for making reamers can be used to make mold cherries. A set of fly cutters will complete the tooling required for making the molds.

The Drill Press

If you have a vertical mill, you can skip this section. If, however, you have a horizontal mill or no mill at all, you will need a drill press to fabricate some of the components of your barrel machine.

The drill press will need to be rated for drills up to at least ½". The motor should have a rating of at least ¾ hp. The table should be adjustable for height but absolutely rigid when locked in position. The spindle should be capable of at least 3" of travel. A rigid setup with vise or clamps is a must for accurate drilling. If you're going to use a drill press instead of a mill for the drilling operations required to build your barrel machine, I strongly suggest that you acquire a compound slide table. One of these will allow you to locate and space drilled holes as accurately with a drill press as can be done with a milling machine. If you use punch marks that were laid-out with manual measurements to locate and space holes in some of the key components of the barrel machine, you will definitely be setting yourself up for alignment problems down the road.

Some drill presses are rated for light milling. If yours is not, do not try to mill with your press by manually feeding the compound slide table. Milling places a tremendous amount of side-stress on the machine's spindle and will quickly ruin a spindle that is not rated for heavy lateral loads.

The 3-in-1 Machine

If you don't have any machine tools yet and you're on a limited budget, you may want to consider a 3-in-1 lathe, mill, drill. As long as each component of the machine meets the requirements listed above, you will be able to use it to build your barrel machine and make accurate rifle barrels with it. When I was setting up my shop and preparing to build my barrel machine, I was on a very limited budget and couldn't afford to buy two or three separate machines. I bought a Smithy Granite 1340 and have used it

exclusively for all machine work in my shop (except the drilling, reaming and rifling of my barrels, of course).

There are two drawbacks to the 3-in-1 machine. First and foremost, I have to spend a lot more time on setups than I would with separate machines. This is because, with only one machine platform available for all operations, I have to completely dismantle a lathe setup to do work with the mill and vice versa. With careful forethought and planning as to the sequence of operations I'm going to perform on a workpiece, I can keep this sort of thing to a minimum but can't eliminate it completely.

The second drawback is the fact that the mill spindle is not fixed. This only causes a noticeable amount of inaccuracy when boring holes more than ½" deep. Since the spindle is not fixed, it tends to flex away from the cutting edge of the boring bar. As the spindle is lowered, the amount of deflection is increased because a greater portion of its length is unsupported. If I bore a hole 2" deep with the mill, the hole will be tapered .002-.003" from top to bottom. The taper can be minimized by running the boring bar into the hole twice at the last depth of cut setting, but it can't be eliminated completely. Milled slots also tend to be skewed just a bit, but not to the extent of bored holes. With end mills, the vast majority of the deflection is directly opposite the direction of feed. However, I do make an effort to keep workpieces as high above the bed of the machine as possible when milling because the less distance the spindle has to be extended, the lower the amount of deflection. A milling machine with fixed spindle and movable knee does not have this problem with tapered holes and spindle deflection.

One plus of the Smithy 3-in-1 machine is that the mill head rotates 360°. This allows me to mill a cut that is over twice as long as the machine's cross slide travel. The procedure for this is to set the mill head at an angle, make a cut, return the cross slide to the starting position, swing the mill head around until the end mill reaches the end of the first cut, then make the second cut. The first time I tried this trick, I was worried that the mill head would be canted differently in each position, thus changing the depth of cut in relation to the workpiece. However, I have found that, at least with my particular machine, the cuts made from the two different head positions are within a thousandth of an inch of perfect agreement, so this is no longer a concern. The same dial settings can be used for gauging the depth of cut at all mill head positions.

Buying a machine tool is, in a sense, a life-long commitment because the machine will outlast you if properly cared for. So anticipate the work you will be doing with your machine over a period of *decades*, not months or even years. If you think that you will need a milling machine more than a lathe over the long haul, a 3-in-1 machine is probably not the best choice for you. If, on the other hand, you will be doing far more lathe work than mill work, then a 3-in-1 machine is a very economical way to get a complete machine shop that will meet your needs for years to come. Now that my barrel machine is complete, I use the mill head mostly for drilling. The workhorse of my shop is the lathe and I am completely satisfied with the lathe component of the Smithy machine. However, a horizontal mill with enough travel to profile octagon barrels in one setup is very high on my priority list. Other than this one specialized operation, the 3-in-1 machine can handle all of my riflesmithing needs. And, it *can* even be employed to cut full-length octagon barrels. It just takes two separate, *very* careful setups to accomplish this particular feat to the standard of accuracy required.

Measuring Instruments

Accurate dimensions are a must on many of the components of the barrel machine and all of the components of the machine's tooling. The only way to produce parts with accurate dimensions is to use instruments capable of making accurate measurements during the fabrication process. I recommend the following instruments as a minimum for aspiring barrel makers.

12" Machinist's Rule

Do not try to get by in a machine shop with the old, wooden ruler marked in sixteenths of an inch that you've had since you were just a little grinner. Machinist's rules are inexpensive, accurate and made of steel for durability. Make sure that you get a rule that is marked in 32nds, 64ths, 10ths and 100ths. All four scales will come in very handy. Get the 12" version so you can measure and scribe guide lines on larger workpieces.

6" Dial Calipers

The same set you use for reloading ammunition will work fine in the machine shop too. If you want a set of the more accurate (and more expensive) calipers that are accurate to .0005", that's fine but a resolution of .001" will suffice. Periodically check your calipers to ensure that they remain zeroed and make sure the jaws stay clean and free of nicks and burrs.

1" Blade Micrometer

This is the instrument to reach for when accuracy counts. The barrel maker's micrometer must have a resolution of .0001". You will not need it often, but when you do, it will be an absolute necessity. Instruments this precise are not cheap or especially durable, so the advice to keep the blades free of dirt, nicks and burrs applies in spades. *Always* check the zero of your micrometer before use. If you're going to be dealing with ten-thousandths of an inch, any deviation from perfection will cost you dearly. Treat your micrometer like the prettiest, most delicate flower the world has ever seen and never leave it out of its case. Put it away as soon as the measurements are complete; this is one piece of equipment that is not designed to be cuffed and scuffed about on a cluttered workbench.

A *blade* micrometer is not absolutely necessary. A micrometer with the standard anvil and spindle will suffice for barrel work. But a blade micrometer can also be used to take case head expansion measurements on fired cartridge cases to gauge the pressure of reloaded ammunition, and who doesn't want to be able to do that? You may eventually use your shiny, new barrel machine to build rifles chambered for wildcat cartridges. If so, you may find reliable reloading information to be pretty scarce and taking case head expansion measurements may be your only good option for working up full-power loads without getting yourself into trouble. I have found that to be the case with the one wildcat-chambered rifle (a Remington M7600 in .375-06 JDJ) that I own. In effect, a blade micrometer kills two birds with one stone– one bird in the machine shop and another at the reloading bench.

Spring Dividers and Calipers

Spring dividers come in very handy to transfer a measurement to multiple workpieces, to layout multiple cuts on a single workpiece and to scribe circles. Spring calipers, both inside and outside, are great for getting rid of metal fast on the lathe. I set my spring calipers to a couple hundredths of an inch shy of the finished diameter and use them during roughing cuts to tell when I'm getting close. Once the calipers slip over or into the workpiece, I know it's time to slow down and prepare for the finishing cut. Some machinists set their calipers to final diameter and use them for the finishing cuts too, but I don't trust myself to do this. I've tested myself by using spring calipers to determine when I've reached the desired dimension. Subsequent measurements on the workpiece reveal that I'm only good to about ±.004" when using this method. That's about the thickness of a piece of paper. I prefer to work to closer tolerances than this. But if you're working on a part that has tolerances you can hit with spring calipers, there's nothing wrong with using this technique. I use dial calipers to measure finished dimensions when tolerances are not too tight. If extreme accuracy is required, I use a micrometer for outside measurements and plug gages for inside.

Protractor

There will be occasions when you need to measure angles with a protractor to set up a workpiece. Make sure your protractor is made of steel, not cheap plastic. Get a model that allows you to measure angles from 0-180°. The protractor must have a flat base that is absolutely square with the 90° mark so you can set it on the machine's table to measure workpiece angle.

Indicators

Dial indicators are an absolute must for accurate machining and barrel making. Indicators are used to center workpieces in the lathe, set vises parallel to the x or y axis, center barrels in the barrel machine spindle, set workpieces in the machine vise at shallow angles, measure tapers and 1,001 other operations that are crucial to good machine work. Seriously, indicators are positively indispensable. If I had to, I could live without any one of the other instruments discussed here, but I'd be absolutely lost without my indicators. And their absence would certainly show in the poor quality of my work. Two indicators with a resolution of .001" and a 1" range plus one indicator with a resolution of .0005" and a .045" range will be sufficient to keep the quality of your work a cut above average. You should have at least two magnetic bases for your indicators. If your mill head tilts left and right, you'll also need a universal indicator holder to mount the indicator to the machine's quill.

Oxyacetylene Torch

In order to heat-treat the barrel machine's tooling, the barrel maker will need an oxyacetylene torch. A propane torch will not produce enough heat to harden tool steel or case-harden mild steel. Obviously, a heat-treating furnace will do the same job, but at tremendously higher expense. One thing that a furnace cannot do is weld. If you plan to fabricate your own tank for the cutting oil/coolant, or weld on any other gunsmithing projects, an oxyacetylene torch will handle this job as well. Yes, a TIG welder would be a lot easier (and some would say better) to use for gunsmithing, but they are also very

pricey. So I suppose the heading of this section should have read "Oxyacetylene Torch *or* Heat-Treating Furnace and TIG Welder". The choice of which tool(s) to use is yours (of course, your bank account will have a say as well).

Barrel Machine

The last, and most specialized, piece of equipment that the barrel maker must have is a barrel machine. The rest of this book will be devoted to the design, construction and operation of a machine capable of drilling, reaming and cut-rifling a solid bar of raw steel. But before we discuss the machine itself, we need to discuss the methods available to fabricate barrels.

CHAPTER 2: Methods of Rifling a Barrel

In making a rifle barrel, the drilling and reaming operations are simple and straightforward. There's a right way to do it and that's that. But rifling is a horse of a different color. There are several ways to form those mesmerizing, spiraling grooves along the length of the bore. Each method of rifling has advantages and disadvantages. Each method has people who swear by it as well as people who swear at it. It's up to the individual barrel maker (and the barrel maker's bank account) to decide which method to use in his shop. The vast majority of contemporary firearms manufacturers use the hammer-forging method to rifle their barrels. The reasoning behind their choice is obvious– they need to produce as many barrels as they can in the shortest period of time at the lowest cost. Quite apart from the very real economic considerations, small custom barrel makers don't employ hammer-forging machinery simply because they have no need to produce so many barrels so quickly. So for most of us, the choice comes down to cut-rifling or button-rifling.

One of the primary considerations in deciding between these two methods is time. When a barrel maker chooses the cut-rifling method, he is obligating himself to invest a considerable amount of time in each barrel. If the barrels will be made only for the barrel maker's own rifles, then the amount of time required to fabricate the barrels is not really an issue at all. However, if the barrel maker intends to sell his cut-rifled barrels to paying customers, then he had better find a specific niche for his products or he won't be able to compete in the marketplace. Examples of such niches are bench-rest rifle barrels and, in my case, large-bore muzzleloader barrels. Neither of these items are readily available at bargain-basement prices because the market for them is not large enough to justify an investment in mass-production machinery.

The other option for the small-quantity barrel maker is button-rifling. This method of rifling requires far less time than cut-rifling, so it is a viable option for those who would like to sell more common barrel configurations. However, nothing in life is free. Button-rifling does impose the additional expense of mandatory stress-relief of the barrel after the rifling operation is complete. This extra requirement is not so much of a handicap to larger custom barrel makers who can afford a heat-treating furnace. But for the small-shop barrel maker, the additional expense must be carefully weighed against the time savings that button-rifling offers over cut-rifling. Quality barrels can be crafted with either method, so it really is up to the individual barrel maker to decide which he'd like to use in his shop. In the following pages, we will take a closer look at the various methods of rifling a barrel so that the decision you make will be an informed decision.

Cut-Rifling

The oldest, and some would say the best, method to rifle a barrel is by the repeated application of a single point hook cutter. With the cut-rifling method, a rifling cutter box is used to hold a hook cutter. The cutter box is constructed in such a way that the bottom of the cutter rests on an adjustable ramp. In the design that I use, the ramp is fabricated with an integral threaded extension at the rear of the part. An indexed nut is fabricated to screw onto the extension. Penetration of the ramp into the cutter box is controlled by adjusting the position of this nut along the length of the threaded stem. The height of the cutting edge above the exterior surface of the cutter box is, in turn,

controlled by the penetration of the ramp. The angle of the ramp is determined by the pitch of the threads on the extension. With the correct ramp angle, one full turn of the adjusting nut will raise the cutter by .001". This allows the nut to be precisely indexed with ten equally spaced marks so that retracting the nut by the distance between any two index marks will allow penetration of the ramp to increase by exactly the amount required to raise the cutter .0001" higher than the previous cut. One ten-thousandth of an inch is the standard depth of cut for each pass of the cutter box through the bore.

The cutter box is mechanically rotated during the cut to provide the grooves with the correct rate of twist for the diameter, length and velocity of the projectiles that the barrel is intended to fire. There are several different types of tooling that can be used to index the rate of twist: a rifling cylinder (or guide bar, depending on which century's nomenclature you prefer to use) system, a sine bar system or a simple rack and pinion system. These different types of tooling will be discussed in detail in the next chapter. Since multiple grooves must be cut in the barrel, it is also necessary to rotate either the barrel or the entire tooling assembly when advancing from one groove to the next. Prior to the Industrial Revolution, gunsmiths did not have accurate pillow block bearings to hold a spindle nor did they have dial indicators to accurately center a barrel in a revolving spindle. Because of this equipment deficiency, they were forced to rigidly fix their barrels to the beds of their machines and rotate the entire tooling assembly when moving from one groove to the next. Today, we do have the equipment necessary to rotate the barrel instead and this proves to be advantageous in several ways.

The geometry of the cutter itself is not universally agreed upon. The source of this contention is the proper rake angle. Negative rake was used on wrought iron barrels of the past and can be used on very mild modern steels to make muzzleloader barrels. Yet modern machine shop practice is to use cutting tools with a positive rake for steel regardless of the alloy or hardness of the steel, so why would anyone use a negative rake? The answer is in the design of the cutter box used with the simple, antique rifling benches. Traditional cutter boxes were made of hardwood or brass and had no ramps or threads or adjusting nuts. They just had a simple slot to hold the cutter. Paper shims were used to raise the cutter on successive passes through each groove. There is no way to lower the cutter with this type of cutter box, so it was run through the barrel with the cutter up in the cutting position on both the forward and reverse stroke. Shaping the cutter's teeth with three-sided files produced a cutter with negative rake on both sides of the cutting edge. This was the simplest method available at the time to produce the cutter. If you have, and intend to use, one of these old-style rifling benches, then a negative rake on your cutter will be appropriate, but you'd better stick with very easily machined steel alloys and the requisite low-pressure black powder loads. Modern, high-pressure smokeless powder loads are not safe in the steel alloys that can be cut fairly easily with negative rake cutters. The geometry of these early cutters and older (or ill-advised) gunsmithing literature perpetuates the belief by some that a rifling cutter should always have negative rake.

When using modern cut-rifling machinery, a positive rake is not only more appropriate, it's absolutely necessary to cut the tough steel alloys used in modern rifle barrels. In fact, no matter what alloy of steel is being used, a positive rake should be used if the cutter box allows retraction of the cutter for the return stroke. The only exception to this rule that I can think of is the special case of making a brass barrel. Brass can be used

for muzzleloading barrels (as long as powder charges are kept very light) and a negative rake is recommended for machining brass. With this one exception, the rake of the cutter should be set at 5° positive rake.

One aspect of cutter geometry that all barrel makers agree on is the need for a relief angle on the side of the cutter that will follow the leading edge of the rifling. Which side of the cutter this relief angle is ground on will depend on whether the rifling will have a right-hand or left-hand twist. The angle of this relief should be 3-5° for centerfire barrels and 2-4 ° for muzzleloader barrels, depending on the diameter of the bore and the twist (angle) of the rifling. The last consideration for cutter geometry is the shape of the actual cutting surface itself. The shape of this surface will determine the shape of the finished groove bottoms. I shape my cutters to cut the bottom of my grooves to a curve that closely matches the radius of the groove-circle. If you'd like to use different groove geometry (such as square-bottomed or rounded), go for it. If the barrel doesn't shoot, you've lost nothing but the hours it takes to make a barrel and then build an entire rifle around it so that you can take it to the range to see if it shoots.

Modern cut-rifling machines use hydraulic power to move the cutter box back and forth through the bore, but this kind of horsepower is certainly not necessary. My machine uses only the horsepower produced by my own right arm turning a hand-crank. I can't speak for every barrel maker, but I *prefer* to power the cut by hand. I can tell just by the feel of the cut what is happening inside the bore. If the cut feels too heavy, I've got a chip jammed into a crevice of the cutter box where it should not be and it's preventing the cutter from dropping fully into position. If the cut feels too light, my cutter is dull and it's time to sharpen it and then run it through that exact same groove again. Hydraulics are not needed to increase the speed of the cut either. Cutting grooves in a rifle barrel is a planing operation. With high-speed steel cutting tools, the maximum speed for planing chrome-moly steel at typical barrel hardness is only 30 feet per minute (fpm). For martensitic stainless steels (such as 416R), the maximum recommended speed is only 25 fpm. I can easily crank my arm fast enough to reach these rates. These figures are for a feed rate of .030" per stroke and a .250" depth of cut. Obviously, rifling cuts do not remove anything like this much material on a single pass, so speeds can be increased a bit to about 40 fpm. Increasing the speed of the cut more than this will only produce tool chatter and rough groove bottoms and it will also dull the cutting edge at a faster rate. And believe me, a cutting speed of 40 fpm will produce enough heat at the cutting edge to leave your cutting oil smoking.

Another form of cut-rifling that definitely does require hydraulic power is broached rifling. The mechanical process of broaching the grooves is exactly the same as for normal cut-rifling except that, instead of a single cutter that can be raised incrementally, the broach contains a succession of incrementally taller cutters aligned one behind the other. There is a set of cutters for each groove that the finished bore will have cut into it. The cutters are aligned with each other at the proper helix angle for the twist rate of the rifling. A hydraulic press pulls the broach through the barrel while oil is being pumped through the bore to clear the tremendous amount of chips out of the way. It would not be all that much more difficult to build a broaching machine than it is to build a normal cut-rifling machine. However, making and maintaining the broach to the standards of accuracy required would be *far* more difficult than making a cutter box and maintaining a single cutter. A horizontal milling machine with lots of table travel, a

universal dividing head and a helical milling drive mechanism would be required to cut the grooves (relief for the lands of the rifling) in the broach to the correct rate of twist. And an oxyacetylene torch will not suffice for heat-treating a cutting tool the size of a broach, so a heat-treating furnace will be required. You will also need a grinding attachment for your mill to grind the correct rake angle on the cutters after heat-treatment. Speaking of the cutters, I cringe when I think of all of those little cutting edges that must be maintained in a razor-sharp condition. If you're thinking about buying broaches from a commercial resource, be prepared for sticker shock. They are frightfully expensive. But if you think that you and your equipment are up to the task of fabricating a broach, broaching will literally shave hours off of the time required to complete each cut-rifled barrel.

Advantages of Cut-Rifling

To my mind, the biggest advantage of cut-rifling is the fact that this process introduces no significant stresses into the steel of the barrel walls. With the cut-rifling method, if you start with properly stress-relieved steel, the barrel will remain as straight as... well, as straight as a rifle barrel during the profiling operation. It will also remain straight during the literal heat of the moment when you're firing one shot after another on the range or in the field. If you read the literature about making rifle barrels that dates from the turn of the 20th century, you'll note that they make quite a big deal out of bending barrels straight before and after all machining operations. With properly stress-relieved steel that has been cut-rifled, all of this barrel bending hoopla becomes completely unnecessary.

Another major benefit of cutting rifling with a single point cutter is the extreme degree of accuracy you can achieve. I'm not talking about shooting accuracy here, but machining accuracy. Because you're only removing .0001" of steel on each pass, groove circle diameter can be held to very tight tolerances– as tight as your measuring instruments will allow. Since the height of the cutter is completely adjustable, the twelfth barrel you make with an individual cutter can be machined to the exact same bore dimensions as the first barrel the cutter ever tasted.

Not only can the grooves be machined accurately, they can also be machined very uniformly. In addition to the depth of any individual groove being very uniform along its entire length, the depth from one groove to the next is also very uniform. When traversing a cut-rifled barrel, the only stress the bullet will feel occurs as it is initially engraved by the rifling. It's all smooth sailing after that.

The most important advantage for the small-shop barrel maker is cost. Cut-rifling machines are less expensive to fabricate and operate than the machines required to produce rifling by any other method. This one advantage makes cut-rifling the obvious, and only, choice for most of us. Luckily, cut-rifling has all of these other wonderful advantages going for it as well.

Disadvantages of Cut-Rifling

There is one, and only one, disadvantage with the cut-rifling method: time. The situation is bad enough when you consider the tremendous amount of time it takes to run the cutter box back and forth in the barrel hundreds of times, but it gets worse when you add in the time it takes to sharpen the cutter dozens of times for each barrel rifled. I get a

backache just thinking about it. But, for the small-shop barrel maker, the advantages of cut-rifling, especially cost, far outweigh this one, although not insignificant, disadvantage.

Button-Rifling

A newer, and far faster method for rifling barrels is button-rifling. This method derives its name from the tungsten carbide forming button that is silver soldered to a rigid rod and pulled through the bore to produce the lands and grooves. The button does not cut steel from the barrel, but rather compresses the steel to form the grooves. Basically, it is a cold-forging operation. The button is shaped somewhat like a football (tapered on each end and fat in the middle) and is ground to form a negative of the finished rifle bore. This means that raised ridges on the button will compress steel to form the grooves of the rifling. Some buttons do not touch the portion of the bore that will become the lands at all and so leave raised burrs at the edges of the lands. Buttons that are ground with a land diameter sizing section that follows the ridged section will press these burrs back down where they belong. The ridges of the button are carefully ground to the exact same angle as the desired rifling pitch. As with the relief angle of the hook cutter used for cut-rifling, the exact angle depends on the bore diameter and desired twist rate. Unlike the relief angle of the hook cutter, which need only exceed the rifling angle slightly to provide clearance, the angle of the ridges on the button must *precisely* match the rate of twist produced by the twist indexing system.

As stated above, the twist rate of the rifling button is controlled by the angle of the ground ridges. But the button can slip and tear the grooves if it doesn't have some help to maintain the proper twist. This helping hand comes in the form of a twist-indexing system mounted to the bed of the machine. The same systems used to twist the cutter box when making cut-rifling can be used with the button-rifling method, except that the tooling must be far stronger when used in conjunction with button-rifling due to the tremendous forces involved with this method. For instance, if a guide bar (rifling cylinder) is used for button-rifling, it must be made of steel whereas hardwood suffices as a material for the cut-rifling cylinder. Again, no matter which system is used to help spin the button, the rate of twist produced by the tooling must *precisely* match the angle of the ridges on the button. If the angles differ by even a small amount, the button and the twist indexing system will be fighting each other, causing slippage and tears in the process.

The lands and grooves of the finished rifle bore are formed by plastic deformation as the button compresses the steel. But the button also causes a certain amount of elastic deformation. After the button has passed through the bore, the deeper layers of steel that were deformed elastically tend to spring back towards their original position by as much as .002". The ridges on the button must be left higher than desired groove depth to counteract this tendency of the steel to snap back into position. The exact magnitude of the elastic deformation and recovery depends on the width and depth of the grooves being formed and the hardness of the barrel blank. Some experimentation with buttons that are incrementally larger in diameter may be required to obtain the correct finished bore dimensions.

The outside diameter of the barrel blank will also affect the amount of elastic deformation and, to a certain extent, the amount of force required to perform the rifling operation. Once the correct button geometry is found to rifle a specific caliber barrel,

each barrel blank used with that button must have the same outside diameter to maintain consistent finished bore dimensions. Additionally, each individual barrel blank must be very uniform in diameter from one end to the other. If you were to button-rifle a barrel that was already profiled to the final exterior contour, the depth of the grooves formed would increase towards the muzzle. Inconsistent groove depth will lead to gas blow-by and very poor accuracy.

Hydraulic rams are used to pull the button through the barrel. For a typical centerfire barrel with grooves that occupy approximately 75% of the bore's circumference to a depth of .003-.004", something in the neighborhood of 10,000 pounds of force could be required to pull the button through the bore. I am being intentionally vague in describing the magnitude of forces involved in this process. I have done this because the actual force required to perform the operation will depend on the total area of button ridges left above bore diameter (number and width of ridges times ridge length), height of the ridges above bore diameter (groove depth) and the yield strength of the steel being used to make the barrel. For instance, if you're making two barrels with grooves covering 75% of the bore circumference, one a .22 caliber with grooves .003" deep and the other a .45 caliber with grooves .004" deep, the larger caliber will require far more force to button-rifle than the smaller caliber. In this case, both the depth of the grooves and the total area encompassed by "75% of the bore circumference" have increased. I'm not going to bore you with the mathematics involved, but suffice it to say that if the ridges of both buttons are ground to a slope of .003" per .100" and the steel being rifled has a yield strength of 110,000 psi, the .22 caliber button will slide right through at 10,000 pounds of hydraulic force while the .45 caliber button could get stuck and some component of your machine may yield instead of the barrel steel. A hydraulic force of over 14,000 pounds could be required for the .45, given these circumstances. However, the amount of force required to pull the button through the barrel will also be affected by the lubricant used to ease the button's passage through the bore. A very good lubricant can reduce the force required to perform the operation by more than half the force calculated to displace dry steel. The point is that if you want to try your hand at button-rifling, make absolutely certain that you know how to calculate the amount of power you will need to make the barrels you want before you start buying expensive equipment.

In order to keep everything running smoothly during the rifling operation, a good quality, high-pressure lubricant must be applied to the bore. The type of high-pressure lubricants used on press molds will fit the bill. If you buy the rifling buttons instead of making your own, you would be well advised to ask the button manufacturer which lubricant he recommends. Also be sure to ask if he knows of a lubricant supplier who is willing to sell small quantities of lubricant to individuals. Industrial lubricants are usually sold in large quantities and most suppliers are less than enthusiastic about selling their inventory in a piecemeal fashion, but it will be well worth the time to try to find one who will. It will cost you a considerable chunk of change to buy a 55-gallon drum of lubricant and it will take a very long time for a small-shop barrel maker to use it all.

During the rifling operation, the barrel blank must be held absolutely still to avoid fluctuations in groove twist rate. There are two types of force being transmitted to the barrel blank during the rifling process: axial and radial. The axial force will try to pull the barrel in the direction of the button's travel and the radial force will try to twist the barrel in its fixture. To counteract the axial force, the barrel blank is butted solidly against a

thick steel pressure plate. This plate must be strong and very securely attached to the bed of the machine because it will take the brunt of the tons of pull being applied to the blank. I have been unable to find out what technique is used with button-rifling machines to counteract the lesser radial force, but I will hazard a guess that tight-fitting collets or chucks would be required and maybe a set-screw or two dimpled into the barrel blank for good measure. I know that I wouldn't feel comfortable with the operation in a less rigid setup than this.

Advantages of Button-Rifling

The primary advantage of button-rifling is the speed and ease of performing the operation. As opposed to the hours of incremental whittling required to cut-rifle a barrel, a button can be pulled through a barrel in less than a minute. And no special skill is required to button-rifle because there is no cutter to maintain in a perpetually razor-sharp condition. Once the button is formed and polished, it can be used over and over again without maintenance until it finally wears below the minimum tolerance for groove depth.

I may take some heat for putting this one in the advantages column, but so be it because I consider it an advantage. Stress-relieving the button-rifled barrel will cause the bore diameter to decrease by .0002-.0003" as the steel relaxes. Why do I consider this an advantage? Because the groove circle must be absolutely *no larger than* bullet diameter (in a centerfire, muzzleloaders are another story) for the barrel to have a chance at being a tack-driver. However, it can be *slightly* smaller. If your button forms a groove circle that exactly matches bullet diameter, the stress-relieving operation will tighten it just a bit, thus ensuring a tight grouping rifle. A tight bore can cause problems when using factory ammunition by raising pressures, especially if the ammo is already loaded hot. But if you're taking the time to make your own rifle *barrels*, there is probably at least a 99.9% chance that you will also be loading your own rifle ammunition. A slightly tight bore will provide you with the best chance of working up very accurate loads, and pressure levels will be safe because the ammunition is specifically tailored to that particular barrel.

Other often proclaimed advantages of button-rifling are the smooth surface of the grooves and work hardening of the bore. However, these advantages are debatable. Yes, cut-rifling leaves tool marks in the grooves, but the marks are very shallow and run parallel with the path of the bullet. They are, in effect, mini-grooves. And as for the work hardening of a button-rifled bore, the mandatory stress-relieving process will temper much of this hardening. I can't say for sure whether or not these advantages really amount to a measurable difference in accuracy or rate of fouling accumulation because opinions and testimonials are too variable to draw any meaningful conclusions. However, I can say that the button-rifling method has several very meaningful disadvantages for the small-shop barrel maker.

Disadvantages of Button-Rifling

The most glaring disadvantage of button-rifling for the small-shop barrel maker is the requirement for stress-relief after the rifling operation is complete. If the stresses induced by button-rifling are not completely relieved, the barrel will likely bend and twist during the profiling operation. Even if bent back to perfect straightness, the barrel will warp as it heats up during firing, causing point of impact to shift. Stress-relief is not a job

for an oxyacetylene torch and a stopwatch, either. The barrel must be stress-relieved in a proper heat-treating furnace with atmospheric control. The temperature must be precisely controlled and held for precisely the correct duration to achieve the desired effect: relief of residual stresses with minimal reduction of hardness and strength. Atmospheric control is also recommended to prevent decarburization and/or scaling inside the bore. Good furnaces can be purchased for the small shop or barrels can be sent out to a commercial heat-treatment facility, but these are expensive options. They seem even more expensive when you consider the fact that there are no stresses to relieve at all when using the cut-rifling method. Maybe I should restate that... The *barrel* will not need to be stress-relieved after a cut-rifling operation. The barrel *maker*, on the other hand, may need a considerable amount of stress-relief by the time the cut-rifling operation is complete (yes, I'm speaking from experience).

Yet another disadvantage associated with the stresses caused by the button's swaging action is the tendency of the bore to expand as the barrel is profiled. And since the barrel walls will be thinnest at the muzzle, this is the place where maximum bore expansion takes place. A belled muzzle will affect accuracy just as surely as a choked muzzle, but with completely opposite consequences. A belled muzzle will cause group size to increase. Proper stress-relief will minimize the amount of expansion, but it can't be eliminated completely. This is why the profiled diameter of many rimfire target barrels increases right at the muzzle; it ensures that the bore will remain tight at the last point of contact between rifle and projectile.

One disadvantage of button-rifling that applies to the mass-production guys as well as the small-shop guys is the difficulty of keeping the grooves uniform from one end of the barrel to the other. Constant pressure must be maintained on the pull rod during rifling or the twist rate can fluctuate slightly, even with the positive drive provided by a guide bar or sine bar. Minor differences in the localized hardness of the steel blank (hard spots and soft spots) will also affect how deeply the button swages the grooves. Some barrel makers who use air gages to assess the uniformity of their barrels claim that differences in groove depth as minor as .0002" can cause bullet instability and inaccuracy. Hard spots and soft spots in the blank can easily cause this magnitude of variation, so it is very important to start with a blank that has been properly hardened and tempered.

Hammer-Forged Rifling

An even faster method to produce rifle barrels is hammer-forging. This method involves using hydraulically powered hammers to forge the barrel over a mandrel. Like the buttons used for button-rifling, the mandrel is a negative of the finished bore with the grooves raised above the lands. But unlike buttons, mandrels are nearly full-length tools and often include a section for forging the chamber as well. Hammer-forging begins with the same steps as the other two methods of producing rifle barrels except that some manufacturers hone the bore after drilling instead of reaming. However, whether reamed or honed, the bore of the barrel blank is machined a few thousandths of an inch *larger* than the finished groove circle diameter. This is done to allow the mandrel to easily slide through the bore for the forging operation. If a chamber is to be forged along with the bore, the hole must be sized .020" larger than the diameter of the base of the cartridge that the barrel is intended to fire.

There are two types of forging machines, radial and rotary, currently in use by the firearms industry. The basics of forging are the same for both types. In both types of machines, four hammers reciprocate open and closed over the barrel blank under enough pressure to cause plastic deformation of the steel. The hammers are equally spaced at 90° intervals so that each hammer is directly opposed by another. The hammers must strike the barrel blank simultaneously to avoid compressing the steel unevenly and possibly damaging the mandrel. A driver and counter-holder are used to hold the barrel blank in position and move it over the mandrel. However, these devices do not prevent the barrel from rotating. The length of the barrel blank grows by about 30% during the forging operation as steel is squeezed and displaced. The barrel must be able to rotate to follow the twist of the grooves as it is driven over the mandrel by the mechanical action of the driver and the plastic elongation caused by the forging process.

As with button-rifling, there is some elastic deformation of the barrel and this allows the bore to spring back slightly so that the mandrel will slide relatively easily through the bore. To ease the mandrel's movement even more, the grooves are formed with at least one side forming an angle of 5° with respect to the radius. Grooves with perfectly parallel sides would not only be more difficult to completely fill by compression, they would also grip the mandrel more firmly and make removing it without damaging something a pretty neat trick. The mandrels used for hammer-forging and the hammers themselves can be made of shock resistant tool steel, such as S1 or S7. Carbide is certainly hard enough for the application, but its extreme hardness causes it to be brittle. By contrast, the shock resistant tool steels are specifically engineered to endure repeated impacts and are used extensively in industries that involve cold die-forming work. However, some manufacturers do make their hammers and mandrels out of carbide, so the material is apparently tough enough to withstand the repeated impacts.

The force required to hammer-forge a barrel is tremendous. As with button-rifling, the force required depends on the bore diameter and tensile strength of the steel. However, since the bore is being forged by forces originating from outside the barrel blank, it will also depend on the outside diameter of the barrel blank both before and after forging. The greater the difference between the diameter of the barrel blank and finished barrel, the greater the force required to compress and squeeze the steel enough to reach the final diameter. Generally speaking, pressure on the order of 100,000-200,000 psi will be required to forge a rifle barrel. Obviously, any machine built to withstand forces of this magnitude, especially at high cyclic rates, must be extremely robust and heavy. Just as obviously, the larger a machine is, the more expensive it has to be because of the costs of manufacturing such a behemoth. This is the reason that only major manufacturers use forgers to make rifle barrels. You have to literally be a millionaire to afford a machine that's this serious about bending steel to its will.

Radial Forgers

The hammers of radial forgers are positively driven both closed and open by a mechanical link to eccentrics. The eccentrics allow the hammers to move through a fixed distance- .080-.200", depending on the machine. The hammer strike frequency can vary from 1,000 to 1,600 strokes per minute. Although the distance of the stroke is fixed, the position of the eccentrics in relation to the centerline of the barrel blank is controlled by a CNC program. This allows the manufacturer to vary the forged diameter of the barrel

along its length while the forging operation is in progress. A radial forger can shape the contour of the barrel's final profile while rifling the bore at the same time. The ability to move the position of the hammers at any point during the forging operation also allows the manufacturer to use barrel blanks with uniform outside diameters when forging the bore and chamber simultaneously. This is a feat that can't be accomplished with a rotary forger. As a result, radial forgers are the more popular of the two types.

Rotary Forgers

The hammers of rotary forgers are enclosed in a stationary housing with fixed rollers. The hammers themselves are spun as a group by dies that fit snugly inside the housing. The hammers are driven closed mechanically when they pass over the high point of the rollers. Centrifugal force serves to open the hammers when they pass over the spaces between rollers. The stroke of the hammers is dependent on the diameter of the rollers and the geometry of the base of the hammers. Hammer strike frequency is determined by the speed at which the hammers are rotated, but is again in the range of 1,000-1,600 strokes per minute. The only way to change the forging diameter with a rotary forger is by spacing the dies. This means that the diameter can't be changed during the forging process. As a result, it is much more difficult to forge chambers with a rotary forger. The outside diameter of the barrel blank must be turned smaller over the portion that will become the chamber before the forging operation is begun. This is the only way that the chamber section of the blank can be forged to the same outside diameter as the rest of the barrel without running into problems with excess steel in places it shouldn't be. Determining the exact pre-forging outside diameter required at the chamber section is a trial-and-error process.

Advantages of Hammer-Forging

Without a doubt, the biggest advantage of hammer-forging barrels is the unbelievable speed with which a plain bar of steel can be turned into a finished barrel. In a matter of minutes, a drilled and reamed (or honed) blank can be transformed from an unremarkable hunk of metal into a completely profiled and rifled barrel that's even chambered for the intended cartridge. The only operations the barrel must undergo after forging are stress-relief, threading for the receiver, crowning the muzzle and a light cleanup of the chamber with the appropriate chambering reamer. Only those who have toiled for hours to produce a rifle barrel by other means can truly appreciate this marvel of modern technology. It really is nearly unbelievable that a senseless machine can use simple (although very intense) pressure to duplicate the work of a skilled riflesmith in a tiny fraction of the time. The careful, thoughtful barrel maker in me, who tends toward perfectionism, rises up in vengeful indignation at the thought of these mindless, upstart machines daring to challenge his ability. However, the frugal, practical rifleman in me welcomes the opportunity to buy brand-new rifles at a cost far less than the proverbial arm and leg. Forgers, as well as a few other modern, time-saving gizmos, make affordable rifles possible. Technology always has been both blessing and curse. I wonder what the *real* barrel makers of the past, who forged their barrels from wrought iron using only fire, muscle, sweat and *real* hammers, would have thought of readily available alloy-steel bars and deep-hole drilling machines... It's thoughts like this that keep me humble.

Another advantage of hammer-forging is the silky smoothness of the bores produced by these machines. With the proper setup, feed rate and frequency of hammer strikes, forgers can produce rifle bores smoother than those achieved by any other method. It's said that if the mandrel is set too far to the rear or one of the other parameters isn't quite right, forgers will leave transverse marks in the bore, but still no worse than the transverse marks left by a reamer. The presence or absence of transverse tool marks does not harm nor help accuracy, but their presence will cause the bore to foul more quickly and be harder to clean. But all things considered, hammer-forging gives a rifle's bore the best chance of remaining nice and clean during a long session at the range.

Disadvantages of Hammer-Forging

This list is, unquestionably, topped by the expense of these machines. Buying a forger will set you back as much as buying three nice homes with a Porsche parked in each driveway. And even if you are financially fat enough to afford the machine, you'll still need to spend a few bucks for a suitable space to keep it. And that bigger-than-a-breadbox space will need a very strong floor to hold up to the weight and vibration of the machine without breaking up. If you invest in a forger, you practically *have* to become a major arms manufacturer to pay the thing off.

The other disadvantage of hammer-forging is the requirement to stress-relieve the barrels after the forging operation is complete. Everything that applied to the stresses induced during button-rifling can be said of hammer-forging in bright, flashing lights. With button-rifling, only the area immediately surrounding the bore is significantly stressed. With hammer-forging, every single atom in the barrel is stressed with a capital "S". To make matters worse, even if the original barrel blank was completely homogeneous before rifling, it likely won't be afterwards. Hammer-forging practically guarantees hard spots and soft spots in the barrel walls. This is the method of rifling that makes re-boring specialists toss and turn at night instead of sleeping peacefully because those hard and soft spots make it very difficult to achieve smooth, uniform results when enlarging a bore to a bigger caliber. Stress-relief goes a long way towards eliminating the trouble spots, but they can't be eliminated completely. Hammer-forging may give a barrel the best chance at remaining clean when firing a multitude of shots without maintenance, but the stress that hammer-forging induces also gives a barrel the best chance at stringing shots across the target as it heats up. This sort of nonsense does not arise with a properly cut-rifled barrel.

CHAPTER 3: Indexing the Twist Rate of Cut-Rifling

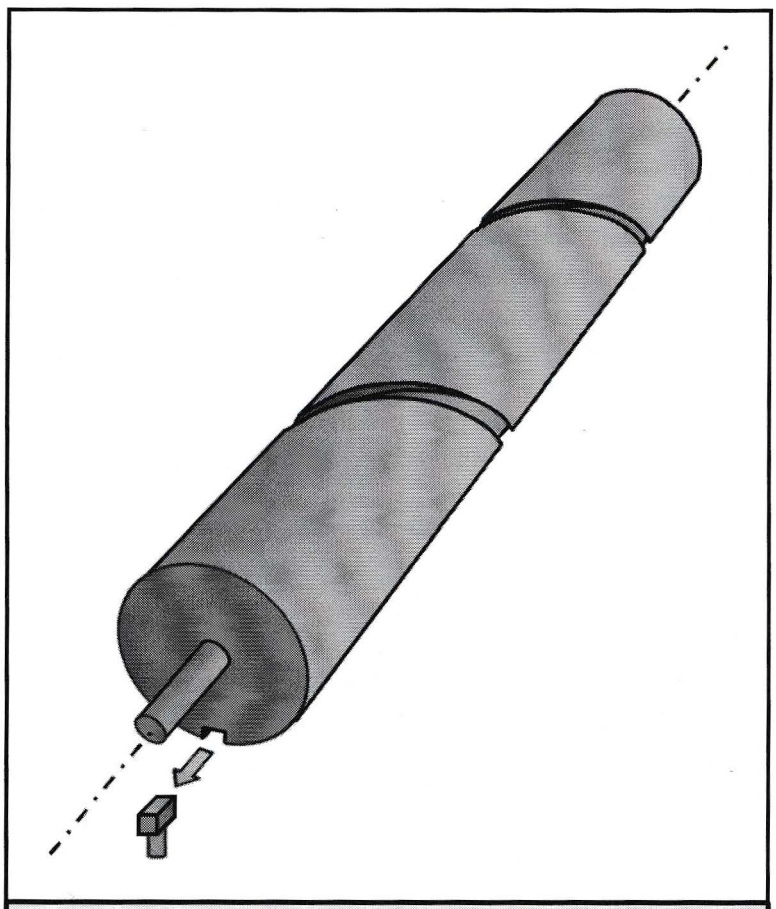
For a small-shop barrel maker, the cut-rifling method is certainly the most practical way to produce accurate rifle barrels. The machinery required to cut grooves in a barrel does not need to be as robust as the machinery for button-rifling (let alone hammer-forging) and can therefore be built less expensively. And the fact that cut-rifled barrels do not need to be stress-relieved also reduces the cost to the barrel maker. However, the barrels produced will be worthless if the twist rate of the grooves is incorrect or inconsistent.

There are several indexing systems that will produce the proper rate of twist in a rifled barrel. Each indexing system has both advantages and disadvantages, but all will produce accurate barrels if set up and used properly. There are several important considerations when choosing an indexing system for the rifling operation. Some systems are more suitable for certain rifling pitches than others because of inherent design limitations or component size requirements. Available floor space is another important consideration. For example, the rifling cylinder indexing system requires a longer machine bed, and more floor space, than other systems. And the sine bar method is best conceived on a purpose-built machine for rifling only. This necessitates enough floor space for two machines– one machine for drilling and reaming and another machine for rifling. These and other considerations will be covered in more detail during the discussion of each indexing system. There may be, and probably are, other twist indexing systems out there, but the indexing systems we will be looking at are the most common and best known.

While there are differences between the various twist indexing mechanisms, the basics are the same no matter which system is chosen. In all cut-rifling operations, a rifling cutter box that is just a whisker under the bore diameter (land-to-land measurement) is pulled and pushed through the bore a number of times to cut the grooves in shallow increments. Rifling cutter box design varies, but all cutter boxes have moveable cutters that are raised a bit at a time to cut the grooves deeper on each successive pass through the bore. And, of course, the cutter box must be mounted to a stiff rod that is well under bore diameter so that it may be pushed and pulled through the bore. These things are common to all cut-rifling systems. The difference between the various twist indexing systems lies in how they impart rotation to the cutter box so that the finished grooves spiral around the bore. And, as you will see, the exact mechanism of rotation has some serious implications for the overall design of the machine and the types of barrels that can be rifled with it. We will be looking at four different mechanisms to impart rotation to the rifling cutter box.

Rifling Cylinder / Guide Bar

The rifling cylinder is made from a round shaft of hardwood, oak being the most common material. The barrel maker uses chisels to cut a spiraling groove along the entire length of the shaft. The pitch of this groove must exactly match the desired rate of rifling twist. The cylinder is then mounted with a steel shaft on each end. These will be the axles on which the cylinder rotates. The axles are used to mount the cylinder on a carriage assembly that supports both ends of the cylinder. Once the cylinder has been mounted on the carriage assembly, the rifling cutter box's pull-rod is attached to the axle at the



The rifling cylinder's axles are held securely on the centerline of the spindle. The rigidly fixed shoe indexes into the groove and causes the cylinder to rotate as the rapid traverse system moves the carriages back and forth along the bed bars.

business end. The entire tooling assembly– cylinder, carriages and rifling cutter box– is pushed and pulled to impart linear motion to the cutter. Rotation is imparted to the tooling by means of a shoe that is firmly fixed to the bed of the machine. This shoe engages the groove in the rifling cylinder and causes it, and the rest of the tooling, to revolve as the carriages traverse the machine bed longitudinally. Historically, rifling cylinders had multiple grooves, one for each groove to be cut in the barrel. This is because the barrel makers of the past had to rigidly mount their barrels to the bed of the machine and rotate the cylinder between cuts to advance the shoe from one groove to the next. Advancing the cylinder to index the shoe in the next successive cylinder groove allowed the next groove in the barrel to be cut. Now, I know from personal experience that cutting *one* groove into an oak rifling cylinder by hand is no day at the beach (more like a couple days at the workbench). So I suspect that the need to cut multiple, perfectly parallel grooves in rifling cylinders goes a long way towards explaining the one-twist-fits-all philosophy that seems to have been pretty common in the 19th Century for multiple calibers of muzzleloaders. Once a rifling cylinder with multiple grooves was completed, any barrel maker with a bit of common sense probably would have been a bit reluctant to undertake such a project again without a very good reason. Fortunately, we now have pillow block bearings that allow us to rotate our barrels and accurately index each groove for successive cuts, so one groove suffices quite nicely. This sure saves a lot of time that would otherwise be spent whittling grooves in rifling cylinders.

Another thing that has changed in the last century or so is the proliferation of sophisticated metal-cutting tools. If you have a horizontal milling machine with enough table travel and the required helical milling attachments, there is no reason to use hardwood. With the proper milling outfit, you could whip out aluminum (to keep the

weight reasonable) rifling cylinders far faster than someone without such a machine can make them out of hardwood. Metal cylinders would also be more durable, although oak cylinders have proven to last for many years and many, many barrels. I do not have a horizontal milling machine, so I have stuck with the traditional hardwood material for my rifling cylinders. So far, they have proven to be completely satisfactory, so you definitely don't need to feel as if metal cylinders are mandatory. However, I assure you that, when the hardwood cylinders start wearing out, I will farm out the job of milling new aluminum cylinders to anyone who has the equipment and can be induced to perform such a task for a reasonable fee. I really don't enjoy the pain-staking work of whittling perfectly straight lines in solid oak cylinders (oak is *very* tough and stringy stuff) and I don't care to go through all of that again.

One of the most challenging parts of making hardwood rifling cylinders by hand is laying out the groove with an accurate twist rate. Trying to make a perfectly straight line wrap around a cylinder is a bit tricky. If you've ever done a wrap-around checkering job on the forearm of a rifle stock, you will know exactly what I'm talking about. There are a few different methods used to lay out the correct twist rate on the cylinder, but all methods involve wrapping a flexible straight-edge around the cylinder and then marking its location. This master line is then used to establish groove width and the groove is cut by hand with a chisel to a depth that will allow full engagement of the twist-indexing shoe with the groove. The groove can be made to have a gain twist by increasing the pitch from one end of the cylinder to the other, if so desired.

The twist indexing shoe that engages the cylinder's groove can be nothing more elaborate than a simple pin fixed to the bed of the machine. If the rifling cylinder is made from aluminum or some other metal, a round pin will prove satisfactory. However, I have found that it is better to use a shoe with more surface area when hardwood cylinders are used. The reason for this is that wood is not a completely homogeneous material; there are seasonal growth rings that have different densities. Wood grows faster in summer than in winter and this rapid growth causes the grain to be more open and less dense. Over time, a simple round pin will wear the summer growth rings at a faster rate than the winter growth rings. If an indexing pin is allowed to wear the summer rings down, this uneven wear will be translated into uneven rotation of the rifling cutter box. This causes wavy rifling. But with a shoe wide enough to span across growth rings, the wear on the cylinder's groove is even and the rifling will not become wavy. Contact between the bottom of the groove and the twist-indexing shoe is another potential cause of wavy rifling. The shoe must be allowed to touch *only* the sides of the groove. If the shoe contacts the groove bottom at any point, the extra drag this creates can cause that particular section of the rifling to lag behind the rest of the groove.

The rifling cylinder method of indexing twist provides very good barrel-to-barrel consistency. Each barrel rifled with a particular cylinder will have grooves with exactly the same twist rate as every other barrel rifled with the same cylinder. The setup is also quick and easy because there are no moving parts on the cylinder that can become misaligned or loose. Just put the cylinder in place on the machine and you're ready for action. As with most other twist indexing mechanisms, the amount of torque on the rifling cutter box is also very consistent for the entire length of the cut. The biggest disadvantage of the rifling cylinder mechanism is the requirement for a very long machine bed. The bed must be long enough to accommodate both the cylinder and an

equal length pull-rod for the rifling cutter box. This means that the machine will take up quite a bit more floor space than a machine built to employ one of the other methods of indexing twist.

The rifling cylinder method is best suited for making muzzleloader barrels because of their relatively slow twist rates. The faster the required twist rate, the harder it is to cut the vertical sides of the groove perfectly straight (perpendicular to the tangent of the groove's centerline) by hand due to the helix pattern. The fastest twist I have cut into a cylinder is one turn in 36", and I don't think I would want to attempt cutting a groove with a twist rate much faster than this. Grooves with slower twist rates are much easier to cut. Of course, this restriction on twist rate only applies to hardwood cylinders with hand-cut grooves.

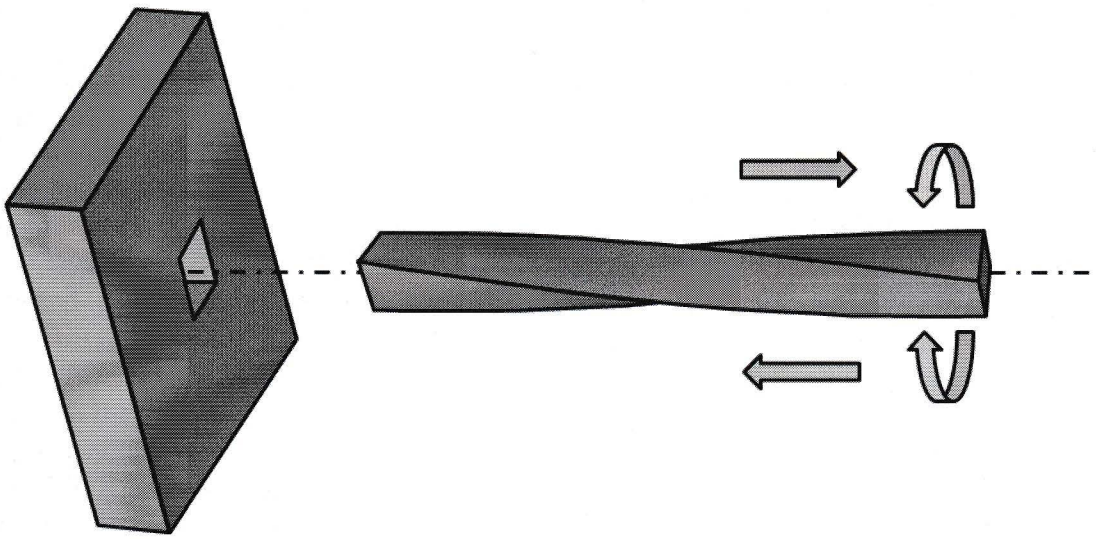
If you plan to make metal rifling cylinders with a milling machine, the twist rate can be made as fast as the milling machine is capable of producing. If you want to make a button-rifling machine, you will need to mill your rifling cylinder (called a guide bar in this application) out of steel. The forces involved in swaging all of the rifling grooves to full depth simultaneously with a button are considerably higher than the forces involved in cutting the grooves one at a time in fractional increments. Hardwood cylinders are simply not up to the task. Also, the indexing shoe must be made of brass instead of steel so that it is the sacrificial part of the system. It is much faster, easier and less expensive to replace a brass shoe than it is to replace a hardened steel guide bar. However, other than the switch to different materials, the rifling cylinder mechanism is exactly the same for both cut-rifling and button-rifling.

Twisted Rifling Rod

The twisted rifling rod method is basically the same as the rifling cylinder method. The difference is that this system essentially combines the rifling cylinder and pull-rod into one component. The rifling cutter box's pull-rod is made from a *square* steel rod that has been twisted to the correct pitch for the desired twist rate. The barrel maker must start with a square steel rod that measures slightly less than bore diameter diagonally from corner-to-corner (not across the flats). This rod is then firmly mounted in a bench vise and twisted to the correct pitch by hand with a wrench. One end of the rod is then mounted to the machine's carriage while the rifling cutter box is mounted to the other end. Rotation is imparted to the assembly by passing the rod through a square-holed fixture that is rigidly mounted to the machine bed. As with the rifling cylinder method, the entire assembly is pushed and pulled through the barrel to cut the grooves. The basic concept of the twisted pull-rod mechanism can be seen in a certain type of toy top that most of us played with as children. These tops were equipped with handles attached to twisted, square steel rods. When the handle and rod were pumped up and down, the twisted rod caused the body of the top to spin as it descended.

As was the case with the rifling cylinder mechanism, the twisted rifling rod method is very old. And it certainly isn't hard to understand why this method was used. Twisting a square rod requires far less time and effort than cutting multiple grooves into a hardwood cylinder. However, there are some pretty obvious problems involved in making a twisted rod that can *accurately* index rifling twist. The foremost problem lies in the difficulty of creating a uniform twist rate along the full length of the rod. You can't just fix one end of the rod in a vise and then crank on the other end with a wrench. This

will create a twist that is most severe on the end being gripped by the wrench with a diminishing rate of twist along the rest of the rod. This is not good if you're trying to cut grooves with a twist rate that never varies. However, if you *want* the twist rate to increase, this is a pretty easy way to get that particular job done. The comparative ease of making twisted rifling rods as opposed to carving rifling cylinders may have been the unintentional impetus for the concept of gain-twist rifling. Whether or not this is the case, it would certainly be easier to make a rod with a gain twist than it would be to make one with a perfectly uniform twist. And, of course, it will be far easier to create a uniform slow twist than a uniform fast twist simply because a slower twist rate will require less total winding for a given length of rod.



Here is the basic concept of using a twisted rod to index the rifling twist rate. As the twisted square rod moves through the square hole in the fixture, it is forced to spin. Moving the rod to the left will cause the side flat to twist up. Moving the rod to the right will cause the side flat to twist down.

Rotation is imparted to the rod and cutter box by drawing the rod through a snug-fitting, square hole in a fixture mounted to the machine bed. The square hole can be fabricated in a couple of different ways. A round hole can be drilled through the fixture with a drill bit that is the same diameter as the measurement across the flats of the rod. Corners can then be filed into the hole with an appropriately sized square file. The second method involves drilling an oversized hole through the fixture and then mounting short sections of square steel bar at the edges of the hole to form the square shape. As with the rifling cylinder mechanism, the fixture must be capable of being rotated and rigidly fixed in several different positions to advance from one rifling groove to the next if the barrel is clamped to the machine bed and cannot be rotated during the rifling operation.

The twisted rifling rod method is another very good system for producing excellent barrel-to-barrel consistency. Every barrel made with a given rifling rod will have the exact same groove pitch. One drawback associated with the use of the rifling rod is that deflection of the cutter box due to torque will not be consistent from one end of the barrel to the other. This is due to the fact that the square-holed fixture represents a fixed

point on the machine and the effective length of the rod is measured from this point. In effect, the rifling rod gets shorter as the rod is pulled through the barrel. And a shorter rod of a given cross-sectional area will be stiffer, and more resistant to torque, than a longer rod. This effect will be slight; however, keep in mind that it is more pronounced with slimmer rifling rods (smaller calibers) than with thicker rods. You will not likely get good results if you try to make a barrel for a prairie dog rifle with a twisted rifling rod, but you won't have much trouble making an elephant rifle barrel with this method.

Because of the difficulties this method imposes on the barrel maker with fast twist rates and small caliber barrels, the twisted rifling rod is best suited to slow-twist muzzleloader barrels. The one big advantage that this method has over the rifling cylinder method is the relatively short overall machine length required. Because this mechanism basically combines the rifling cylinder and pull-rod into a single unit, the length of the machine can be reduced by nearly half that required for a machine that employs rifling cylinders. So, if you want to make muzzleloader barrels and you are short on floor space, this method is certainly worthy of consideration.

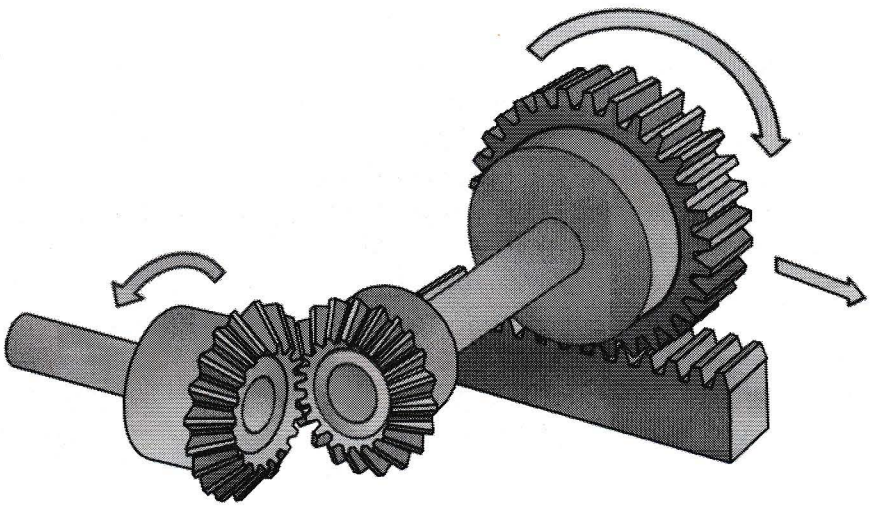
Rack & Pinion

This mechanism employs a rack mounted to the machine bed and an associated gearing assembly to impart rotation to the rifling cutter box. An axle is mounted on the carriage perpendicular to the bed bars in pillow-block bearings or some other suitable fixture. A spur gear is mounted on the axle to the outside of the carriage. This gear engages the rack and provides the primary driving force for the cutter box assembly. A miter gear is mounted centrally on the axle. This miter gear engages a second miter gear that is mounted to the rear end of the pull-rod/cutter box assembly to drive the rotation of the cutter box as the carriage is moved fore and aft.

This mechanism provides a very easy way to produce an extremely uniform groove twist rate. Unlike the hardwood rifling cylinder and twisted rifling rod methods, no special skill is required to fabricate an assembly such as this. Simply purchase the appropriate mass-produced gears, then accurately locate and mount them on the machine and you're in business. There is no danger that the twist rate will change from one end of a barrel to the other. The rate of twist is determined by the circumference of the spur gear that engages the rack. The twist rate will precisely match the spur gear's circumference, assuming that both miter gears are the same diameter. For instance, if you want a fast 9" twist for small-bore barrels, a spur gear with a pitch diameter of 3" (circumference 9.425") will get the job done quite nicely. Likewise, a gear with a pitch diameter of 4" will produce a twist rate of one turn in 12.566" for larger calibers.

The rack and pinion mechanism has several advantages over other methods. As mentioned above, it is very easy to set up such a system to accurately index groove twist rate. This system can also be used on a machine with a relatively short bed. Also of key importance is the fact that, in terms of the twist rates required by centerfire barrels, the rack and pinion is readily adapted to a 3-in-1 machine that can perform the three operations of drilling, reaming, and rifling. This mechanism can also be easily adapted to different twist rates for different barrel calibers by raising or lowering the rack on the side of the machine's bed to allow the use of spur gears with various pitch diameters.

However, there are some applications for which the rack and pinion are not ideally suited. First and foremost in my mind as a large-bore muzzleloader guy is the fact



This illustration depicts the rack & pinion method. In the interest of illustrative clarity, the rack has been abbreviated and the carriage has been eliminated completely. Also for visual clarity, the axle between the spur gear and its associated miter gear has been included, as has an abbreviated section of the rifling cutter box pull-rod in the second miter gear. The rack is rigidly mounted to the side of the machine bed. As the carriage moves away from the spindle for the cutting stroke, it takes the gears along with it, causing them to rotate in the directions indicated.

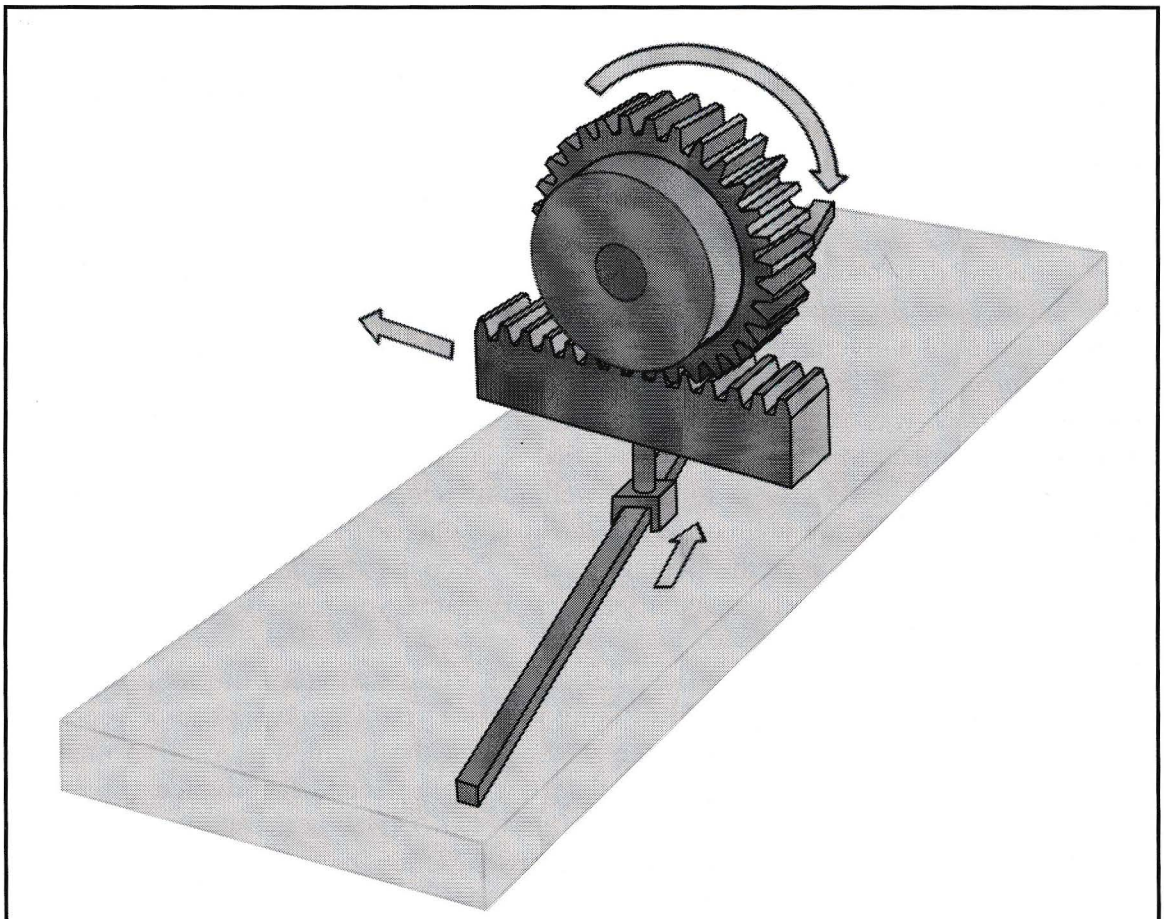
that very large spur gears are required to cut slow-twist grooves. For example, it would take a spur gear with a pitch diameter of just over 33" to make a 4-bore, round ball barrel with a 104" twist. A gear that large would not only be cumbersome, it would also require a more complicated design for the machine bed and bench. On a dedicated rifling machine, that's not such a bad thing. But on a 3-in-1 machine, drilling is the most important and complicated operation and the machine should be built to drill first and foremost. Another potential disadvantage of the rack and pinion system is that it is not suited to making gain-twist rifling. If you have no interest in gain-twist barrels, then this is no problem at all. However, if you'd at least like to have the option of experimenting with gain-twist, then the rack and pinion is not for you.

Sine Bar

The sine bar mechanism uses an adjustable steel bar mounted to the bed of the machine to index the rifling twist. A sliding rack is mounted on the carriage perpendicular to the machine bed. This rack is equipped with a shoe that passes through a slot in the carriage and envelopes the sine bar. As the carriage is moved longitudinally along the bed of the machine, the shoe follows the angle of the bar and slides the rack along with it. On the top of the carriage, a spur gear mounted to the end of the rifling rod engages the rack and rotates the entire cutter box assembly as the carriage moves back and forth along the machine bed.

There is an alternate layout for a sine bar machine that employs a wide fixture that straddles the bed of the machine. This fixture is used to hold the sine bar *above* the

carriage. The advantage of this setup is that the bed of the machine can be made narrower because the sine bar can be allowed to overhang the bed bars if it is mounted above them. When mounted to the bed of the machine, the sine bar (and the total lateral length of travel for the rack's shoe) must fit between the bed bars, thus requiring a wider bed. The disadvantage of this alternate setup is that the fixture itself must be fairly wide to clear the carriage and rack and it must be pretty stout in order to hold the sine bar rigidly. The relative merits and drawbacks of the two designs will have to be weighed by each barrel maker according to his own personal requirements, but either arrangement will accurately index the twist of the rifling cutter box.



Here is one version of the sine bar method. As before, the rack has been abbreviated and the carriage has been eliminated for visual clarity. This time, the rifling cutter box pull-rod also had to go. The shoe is fixed to the bottom of the rack and the sine bar is mounted to the machine bed at the appropriate angle. As the carriage moves away from the spindle, the shoe grips the sine bar and causes the rack to slide laterally across the carriage. This, in turn, causes the spur gear to rotate in the direction indicated.

The sine bar method provides a relatively easy way to set up the machine to cut a given rifling pitch. However, unlike the rack and pinion assembly, the spur gear's pitch diameter does not stand alone in determining the rifling twist rate with the sine bar method. Instead, the pitch diameter of the spur gear works in concert with the angle of the sine bar to determine how quickly the rifling cutter box will rotate. When the carriage-mounted rack moves a distance equal to the circumference of the spur gear being used,

the gear and rifling cutter box will rotate one full revolution. The rate at which the rack slides laterally for a given length of longitudinal carriage movement is determined by the angle of the sine bar. A greater angle (measured from the longitudinal axis of the machine) will cause the rack to move farther for a given amount of carriage movement. This, in turn, will cause the rifling cutter box to rotate at a faster rate. The distance the carriage will need to move longitudinally to cause the rack to move a distance that is precisely equal to the circumference of the spur gear can be calculated using the sine function of the angle at which the bar is mounted to the machine– hence the name sine bar. If you are not mathematically inclined, calculating the proper setup angle may be difficult at first, but you will get the hang of it rather quickly so don't let this be the deciding factor in choosing your rifling twist-indexing method. Keep in mind that, once the machine is constructed, you *must* change the pitch of the sine bar to change the twist of the rifling. Once the machine's carriage is set up to use a spur gear of a given pitch diameter, a gear with a larger or smaller pitch diameter will move the rifling cutter box above or below the centerline of the barrel spindle and render it incapable of sliding through the bore.

The one drawback to using the sine bar method is that switching from one twist rate to another and then back again can very easily lead to slight differences in twist rate from one barrel of a given rifling pitch to the next. Even with indexing marks on the bed of the machine, it will be rather difficult (and time-consuming) to get the sine bar set up exactly as it once was after it has been moved to cut a different pitch in a barrel. This could potentially lead to making one barrel that is an absolute tack-driver while another seemingly identical barrel refuses to group well no matter what type of loads you feed it. However, this disadvantage will not be a factor if you choose to make only one caliber of barrels, all of which will have the same twist rate. Once the sine bar is set at the correct angle, it can be left in place permanently and every barrel you make will have the same twist rate.

One of the advantages of the sine bar mechanism is that you will find it very easy to create gain-twist rifling, if this sort of thing interests you. Gain twist can be produced by bending one end of the sine bar to the side. Start with the angle necessary to cut the slowest portion of the rifling. Then calculate the angle needed to produce the fastest portion of the twist. The difference between these two angles is the angle of the bend required to create the correct rate of gain in the twist. Once the machine is set up to cut rifling with the sine bar, this is probably the easiest and most accurate method to produce gain-twist rifling of any of the mechanisms we have discussed.

As mentioned briefly in the introduction to this chapter, the only real disadvantage to the sine bar method for the small-shop barrel maker is the fact that this mechanism really does need to be set up on a purpose-built rifling machine. The problem with trying to adapt the sine bar method to a 3-in-1 machine is that the leadscrew used to feed the drilling and reaming tools sits precisely in the location where it would be easiest to mount a sine bar. If you would like to use a sine bar to index your rifling on a 3-in-1 machine, the most practical way to do that would probably be to make the leadscrew easily removable. That way, when the drilling and reaming operations are complete, the leadscrew can be gotten out of the way so that the sine bar can be brought into play. If you're going to try this, just know in advance that this will add a considerable amount of setup time to the job for each barrel that you make. You will also have to design some

sort of indexing mechanism into the machine that will allow you to repeatedly and accurately mount the leadscrew on the exact centerline of the machine. If you have the available space, you will save yourself quite a few headaches by building a separate machine for rifling if you want to use the sine bar method to index the rifling twist.

One of the great advantages of the sine bar method is that there is no rate of twist that is too fast or too slow. Whether you are making .22 caliber centerfire barrels with a 7" twist or 4-bore muzzleloading elephant rifles with a 104" twist, the only change that needs to be made to the machine setup is the angle of the bar. If you would like to experiment with all different kinds and calibers of barrels, including gain-twist barrels, then the sine bar mechanism will allow you to tinker to your heart's content without having to build a separate machine with a purpose-built mechanism for each type of barrel you make. I designed my machine to use the rifling cylinder method because my interest is centered on making large-bore muzzleloader barrels and I also didn't have the space for two machines. However, I will probably build a separate sine bar rifling machine at some point in the future simply because such a machine would make it so very easy to try out different ideas.

CHAPTER 4: The 3-in-1 Barrel Machine

The drilling, reaming and rifling of rifle barrels are all very specialized operations that are not required or typically encountered in general machining. Sure, machinists drill and ream holes all the time. But those holes are typically only a few inches deep, at most. Lathes and mills can handle the machining of shallow holes with little difficulty. The trick when it comes to making rifle barrels is to machine perfectly straight holes with depths measured in *feet*, not inches. This sort of specialized operation requires some very specialized equipment. In fact, the machines used to perform these operations are so specialized that they are of no use for anything other than making rifle barrels. This narrowly focused purpose allows the design of the machine's components to be very basic because they only have to be very good at doing one thing.

When building a rifle barrel machine, or any other kind of machine for that matter, it is very important to take some time to design all of the components of the machine before actually fabricating or purchasing any of them. The reason for this is simple– all of the pieces work together to make a functioning whole. Because of this interdependency, the size, shape and placement of each component will affect the size, shape and placement of every other component.

The components that you will be fabricating yourself can be made to any dimensions that you require (within practical limits). However, the dimensions of the components that you will be purchasing do not give you the same degree of flexibility in design. After roughing out the general size and layout of your machine, you will need to do some homework to determine the dimensions of the gears, pulleys, bearings, motors and other assorted items that will be outsourced to finish your machine. I'm not talking about the very basic dimensions, such as a 2 $^{1}/_{16}$" bore through the raceways of the bearings for the spindle, but rather dimensions such as the center height of the bearing race above the base of the bearing and the spacing of the bolt holes through the base. *These* are the types of dimensions that will affect the design of your machine. Note carefully that I did not say that you will need to purchase the components and have them in your hands while designing the machine. Just get the dimensions of the parts now so that you can incorporate them into your design. When the design is finalized and you're sure that everything will fit together as it's supposed to, then the time has come to start buying the components that you don't intend to make yourself.

But the first step is to sketch out the basic design of your machine. The starting point of the design is not the machine bed or even the tools for drilling, reaming and rifling. The only point at which to begin designing a purpose-built machine of this sort is at the finished product itself. In this case, this means that the machine's design *must* start with the barrels that you intend to make. The machine must be made to accommodate the barrel, not vice versa. I believe this is known as reverse engineering in some circles. I call it common sense. I will not be providing a detailed listing of the dimensions of my machine's components because that would be a very good way for me to get you into trouble. My machine is designed to make *my* barrels and the same component dimensions may not work for you. The specific form of every component of your machine must follow the specific function it will have to serve to achieve *your* specific end. Along the same line of thought, if your specific end is a button-rifling machine, this basic blueprint for a cut-rifling machine could be adapted to serve that function without much trouble.

To put it in a vastly oversimplified nutshell, you'd just need to add a pressure plate and a hydraulic press to my machine with its rifling cylinder twist indexing system. Just remember that the entire machine will need to be much more robustly constructed to handle the terrific forces involved with cold-swaging steel.

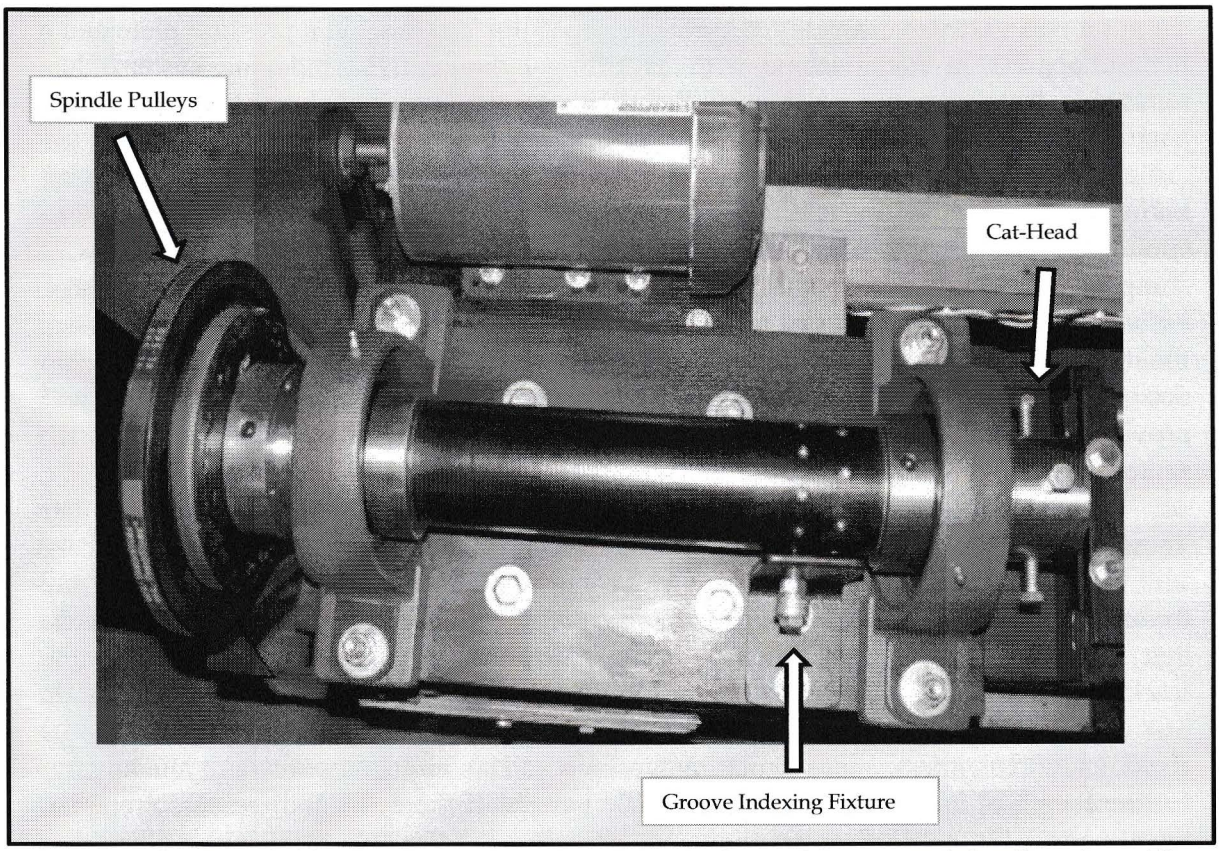
But before you can design the components and layout of your machine, you must know what each component is required to do, both individually and as an assembly in conjunction with other components. In this chapter, we will look at what kinds of components are required to perform the basic tasks of machining rifle barrels. Those basic tasks are work-holding, tool-holding and tool-feeding. Once you know the basic functions that your machine's components will be called upon to perform, you can begin designing the layout and dimensions of the machine. The last section of the chapter will provide a few helpful tips and techniques to align all of the machine components on the same centerline.

Work-Holding Components

The machining of a rifle barrel is accomplished by moving a cutting tool to, and through, the workpiece while one of the two is being rotated. There are drilling machines that place the drill in a spindle so that it can be rotated while being fed into the workpiece. These machines work well within certain limits. Generally speaking, they do best when machining relatively short holes. The other option is to hold the tooling in a fixed position as it is fed into a rotating workpiece. This arrangement works much better for the length of holes required to make rifle barrels. If the drills and reamers are spun, their shafts will tend to flex and bow and this can cause the hole to meander off-center. This flexion is most pronounced with the drills because they are inherently out-of-balance when spun at high speed due to the V-groove that is pressed into their shanks to allow oil and chips to flow back out of the hole. It is much better to hold the tooling stationary (in relation to the carriage) and spin the barrel blank. It is also best to rotate the barrel from one indexing point to the next when performing the rifling operation instead of advancing the entire tooling assembly. So the work-holding components of the machine must include a rotating spindle, a motor with its associated belts and pulleys, and an indexing fixture to positively lock the spindle at discrete increments for the rifling cuts.

The Spindle

The spindle must be capable of running perfectly true as it is rotated about the centerline of the machine. It must be straight enough not to induce vibration and wobble that would cause holes to run off-center, causing poor quality work and possibly damaging the cutting tools in the process. These criteria mandate the use of a fairly stout piece of seamless tubing to fabricate the spindle. The best choice of material to fabricate the spindle is DOM tubing. DOM tubing is manufactured to tolerances of straightness and wall thickness uniformity that will allow it to be made into a spindle with an absolute minimum of machining work. The only criteria involved in selecting suitable DOM tubing is the diameter of the bore and the wall thickness. The bore should be at least ⅛" larger than the largest diameter of barrel blank that you want to use. The walls of the tube should be thick enough to provide rigidity and enough meat for threaded holes passing through them to fully support the cat-head bolts. I chose tubing with ½" walls to meet these demands. For contemporary barrel lengths, a 24" spindle will be sufficient to fully



support the barrel blank. If you have an interest in making muzzleloading longrifle barrels of 40" or more, a slightly longer spindle may be called for.

Since the spindle must be capable of rotating, it needs to be mounted in a pair of pillow-block bearings. Journals are cut on each end of the spindle to provide a light press-fit for the inner races of the bearings. The journals must be long enough to allow the bearings to slide onto the spindle sufficiently far for other components to be mounted on the outboard sides of the bearings. Expensive, special-purpose bearings are not required. Standard, single-row pillow-blocks will work just fine and will last for a lifetime if properly cared for and lubricated. In addition to the friction of the press-fit, the bearings should be equipped with set-screws that can be dimpled into the spindle to help ensure that the spindle can never slip within the bearing races.

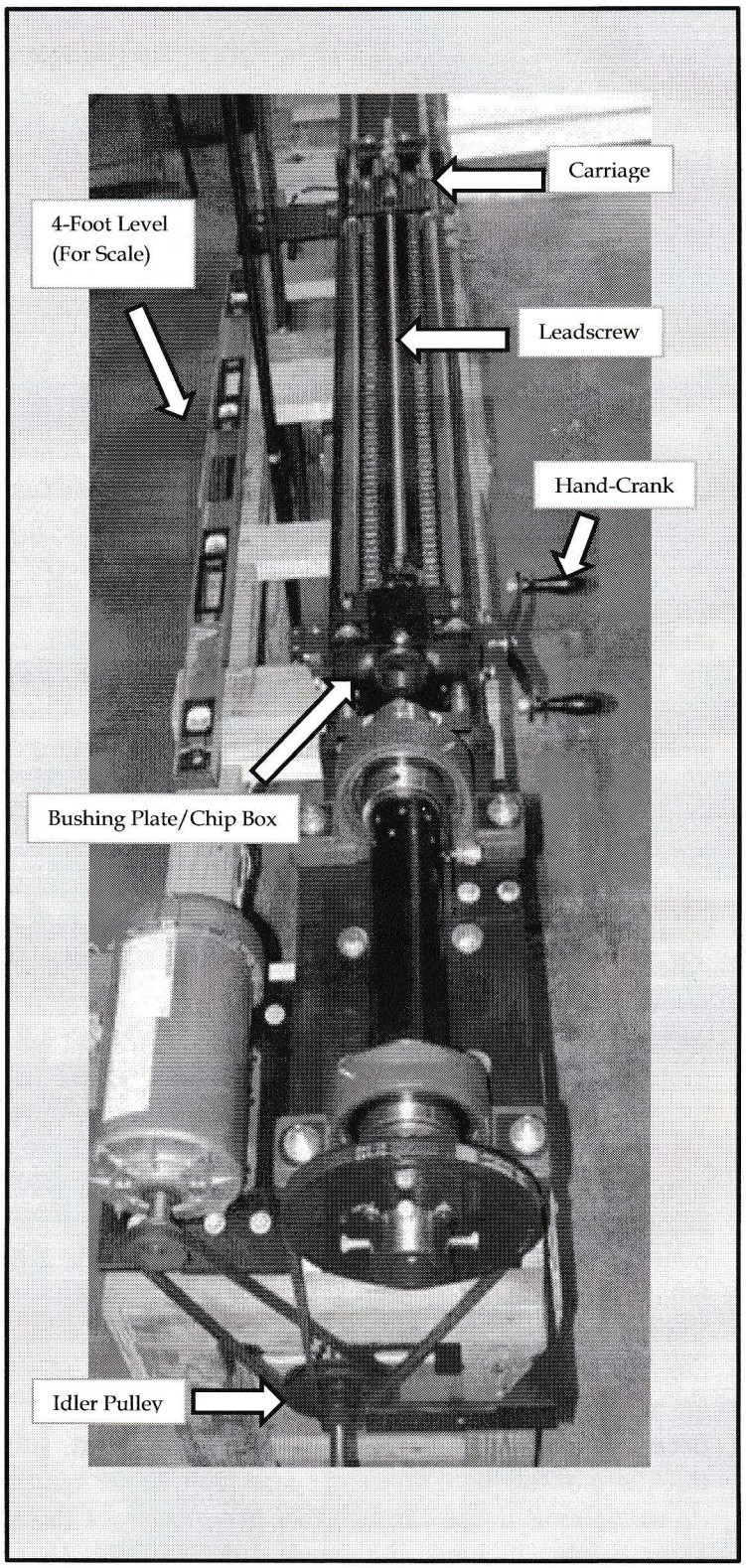
In order to hold the barrel blank firmly in place on the exact centerline of the machine, the spindle must be equipped with adjustable clamping features like a four-jaw lathe chuck. In fact, you could mount a four-jaw chuck to each end of the spindle if you can find chucks that are the right size. However, this will add quite a bit of cost to the spindle, and chucks are not absolutely necessary. I fashioned my spindle with a cat-head at each end and the clamping force they provide has proven to be quite sufficient to hold barrel blanks in place for all machining operations. The twin cat-heads allow me to use dial indicators to get both ends of the barrel blank running perfectly true to the centerline of the spindle. Locking nuts should not be used on the bolts of the cat-heads. The pull exerted on the cat-head bolts by lock-nuts can cause the bolts to retract very slightly, shifting the barrel blank off of the centerline of the machine and negating all of the careful work you did to get it there.

If, like me, you do not have a milling machine equipped with a universal dividing head to index the location of the threaded holes for the cat-head bolts, there is another way to accurately locate the holes. Take a thin strip of paper and wrap it around the bearing journal. Then use a very sharp pencil to mark the paper where it overlaps (at the very end of the strip). Next, use a dial caliper to accurately measure the distance from the end of the strip to the mark. This is an exact measurement of the circumference of the journal. Divide this measurement by four and set your calipers to precisely this distance. Now, starting at the end of the strip, use your calipers to mark off four equal segments. Wrap this strip of paper back around the journal and tape it in place with the edge of the paper (the edge with the tick marks) set at the location on the journal where you want to place the cat-head. Now make a light punch mark at each tick mark (only three tick marks are necessary, the fourth punch mark is made at the end of the strip). This will accurately locate the relative position of each individual cat-head bolt. When mounting the spindle in the mill vise to drill and tap the holes for the bolts, use a top dead-center punch with the punch point resting in one of the punch marks and level the spindle. For those of you who don't know, a top dead-center punch has a level built into it to find the top of a gun barrel when the gun is mounted in a vise. Presumably, the vise jaws will be perfectly vertical during this operation. After leveling, the spindle is centered under the mill spindle and the punch mark is accurately located along the x-axis for drilling. When one hole is drilled and tapped, loosen the vise and rotate the spindle to advance the next punch mark and level the spindle with the top dead-center punch as before. After tapping the last hole on one end of the spindle, use the top dead-center punch to mark the location of the corresponding hole on the other end of the spindle. Your layout for that end of the spindle will start from that point and this will ensure that the cat-head bolts are precisely aligned with the corresponding bolts on the other end of the spindle. Yes, this technique takes a considerable amount of time and patience, but I know of no better way to locate the cat-heads without a universal dividing head.

The spindle is driven with pulleys mounted on the same journal as the outboard bearing. The pulleys bolt to a stop collar that has been drilled and tapped for four screws. After drilling and tapping, the collar is press-fit onto the journal and locked with a set-screw just like the bearings. The pulleys on my machine are modified, store-bought specimens. I made them by cutting out the central hubs and then brazing ¼" steel plates to them so that the mounting bolts will have something substantial to clamp onto. Before brazing the plates to the pulleys, I turned both the outside diameter and inside bore of the plates on the lathe so that they would center precisely in the pulleys and fit snugly on the spindle journal. This seemed like a quick, simple way to fabricate my pulleys. However, brazing steel to cast iron is not an undertaking to be taken lightly. If I had this task to do over again, I would buy some aluminum plate and make my own solid pulleys on the lathe.

The spindle bearings are mounted on a ⅝" steel base-plate. The reason for mounting it on a plate is twofold. First of all, the bolt holes in the bases of the bearings are spaced wider than the 8" bed of the machine. The plate provides the extra width necessary to solidly mount the bearings. Second, and perhaps of more importance, the thickness of the plate raises the centerline of the spindle by ⅝" and this provides the extra room underneath the carriage that is required for the leadscrew and half-nut. Without the extra height, it would be much more difficult to fit all of the required components

underneath the machine centerline. The base-plate can be fabricated out of ordinary cold-rolled steel plate. There is no need to surface grind the plate because any irregularities in the plate can be compensated for with shimming material.



The Spindle Motor

The spindle motor horsepower rating is based upon the power required to overcome the thrust and torque of deep-hole drills. Because deep-hole drills are absolutely free-cutting from the outer edge of the hole all the way to the center and the feed rate is so fine compared to that used for regular twist drills, the horsepower requirement of the motor is surprisingly low. If you intend to build a machine of your own, I strongly encourage you to do your homework and calculate the power necessary to run the spindle at the speeds and feeds that you feel are appropriate for the size of drills you will be using. But unless you're running a very large drill diameter with faster speeds and heavier feeds than recommended, you will find that a 1hp motor will prove quite sufficient for all of your drilling requirements. And, of course, the horsepower required to perform the reaming operation is even lower than that required to drill.

The speed rating of the motor should be selected based upon the recommended cutting speed for the diameter of drills that you will be using. If you plan to make small-caliber barrels only, you may want to use a motor with a speed of 3,200-3,600 rpm. However, if you plan to make large-caliber

barrels, a speed rating from 1,200-1,800 rpm will serve you better. No matter what motor speed you choose, keep in mind that the reaming speed will need to be considerably lower than the drilling speed. This requirement for at least two different cutting speeds necessitates the incorporation of a pulley system to increase or decrease the speed of the barrel spindle as required by the tooling.

My machine is designed to make large-bore barrels only, so it uses a motor with a mid-range rating of 1,725 rpm. Since this is more than fast enough to drill and ream the barrels that I make, my machine employs an idler pulley system that acts to reduce the speed of the workpiece. This intermediate pulley arrangement not only reduces rotational speed to the appropriate level, it also provides a convenient place to adjust belt tension and allows belts to be changed for different sized pulleys with the loosening of a single bolt. There is no need to loosen the motor or the spindle from their bases in order to change belts. The idler pulleys are mounted on a ¾" shaft. The shaft is held in position on a ½" steel plate that bolts snugly to the machine bench. Flange bearings on each side of the plate support the shaft at two points to keep vibration and chatter to a minimum. A single ½" bolt anchors the plate to the bench by passing through a slot in the plate that is 3" long and ½" wide. This slot allows the plate and pulleys to be moved up and down as well as side to side to achieve the correct tension on both drive belts simultaneously when using different sized pulleys.

Groove Indexing Fixture

The fixture for indexing the spacing of the rifling grooves works in concert with a set (or sets) of indexing holes on the barrel spindle to accurately locate the grooves. The fixture itself is comprised of a vertical steel plate that has a set-screw or plunger passing through it. The screw or plunger passes through the plate and protrudes from the other side far enough to engage the indexing holes on the spindle and mechanically lock the spindle in position. If a set-screw is used, the vertical plate will be threaded for the screw. If a plunger is used, either a cam-lock or a stiff spring can be used to force the plunger into engagement with the spindle. The indexing plate is mounted to the same base plate that is used to anchor the spindle bearings, thus ensuring that the agreement between the spindle and the indexing plate won't shift.

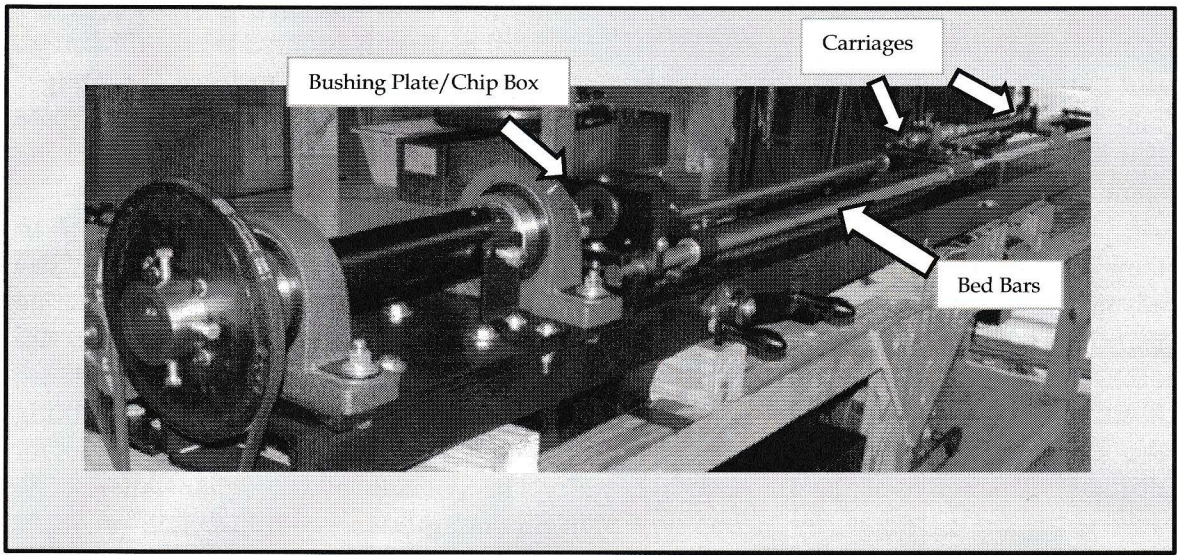
The indexing holes on the spindle may be drilled into the spindle body itself, or they can be drilled into a collar that is slid onto the spindle and locked into position. The advantage of drilling the holes directly into the spindle body is that there is no separate part that can become loose and move while in the process of rifling a barrel. If such a slip occurred, it would be very hard to get the collar locked back into position exactly where it once was and the barrel would likely have to be discarded. The advantage of drilling the indexing holes into a sliding collar is that the collar is much easier to set up for drilling the holes than the full-length spindle. The position of the collar can also be adjusted if the holes for the indexing plate's mounting bolts weren't drilled precisely where they were supposed to be. Either method will work, so choose the one that you think is best.

The indexing holes on my machine are drilled directly into the spindle body. There are two sets of indexing holes– one set for 8 grooves and another set for 10 grooves. These same holes can also be used to index 4 or 5 grooves by skipping every other indexing hole. I have had no reason to do this yet, but the option is available. The

indexing holes were located using the same technique of wrapping the spindle with a slip of paper and dividing the circumference into equidistant segments (8 and 10 segments instead of 4) that was used to locate the cat-head bolts. The two sets of holes were laid out from the same starting point on the spindle body, meaning that the holes line up with each other here. Since both of my hole patterns contain an even number of divisions, there is another set of aligning holes exactly 180° around the spindle from the layout starting point. One of these matching pairs of holes is marked with a white line painted between them. This is the take-off point for rifling. Every time this mark comes around during the rifling process, the hook cutter of the rifling cutter box is set .0001" higher for the next round of cuts through the grooves. One minor, yet important, note about the groove indexing fixture: *do not forget* to remove the set-screw or plunger from the fixture plate before starting the spindle motor for drilling. Starting the spindle motor with the spindle mechanically locked is not a very good idea, to say the least.

Tool-Holding Components

The main purpose of the machine's tool-holding components is to provide a solid platform to rigidly fix the cutting tools on the centerline of the barrel spindle. Alignment and solidity are of paramount importance here. As mentioned above, the machining of long, narrow holes is accomplished to the highest degree of accuracy when the cutting tools are held stationary (no radial motion) and the workpiece is rotated. This is fortunate, because it greatly simplifies the design and construction of the tool-holding components. It is far easier to build an immovable clamp than it is to build a clamp capable of rotating at high speed without vibrating itself loose. The tool-holding components of the machine include a smooth, level bed on which the tooling can travel, a carriage to ride on this bed and tool-specific adapters to firmly grip and guide the cutting tools.

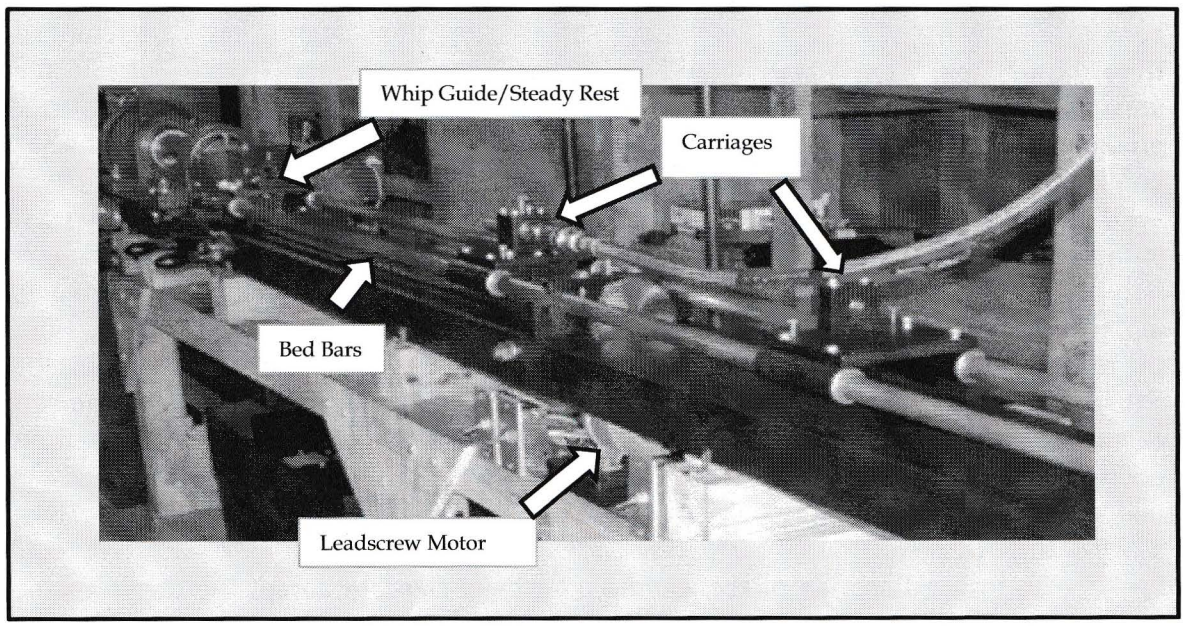


The Machine Bed

Since the bed bars are the base for all of the tool-holding components, we will look at those first. The bed bars are made of polished shafting material. They must be smooth and absolutely straight. The diameter of the bed bars is not especially critical. A one inch diameter is sufficient but larger diameters will certainly work. The thing to keep

in mind when selecting bed bar diameter is that the larger they are, the less space you will have available between them for the other components, such as the rapid traverse chains and the leadscrew. Also remember that the larger the bed bars are, the lower they will have to be mounted to get the universal block of the carriage on the centerline of the spindle. But as long as the diameter of your bed bars does not interfere with the placement of other components, any size you choose should prove satisfactory.

The bed bars are anchored to the machine bed using steel mounting blocks. If you plan to use the rifling cylinder mechanism to index rifling, you will need three of these blocks. If you will be using one of the other mechanisms, only two mounting blocks will be needed. When cutting the slots for the bed bars into the blocks, all of the blocks should be placed in the milling vise at once so they can be machined in tandem. This will ensure that the slots in the blocks will be the same width and have the same center-to-center spacing. This will go a long way towards simplifying bed bar alignment. The bed bars are held in position in the mounting blocks by strap clamps. Each mounting block is paired with a strap clamp and the two are secured to the machine bed by two bolts. The strap clamp for the center mounting block on my machine is tapped to accept the twist indexing shoe that drives the rotation of the rifling cylinder. This is not the only location where this device can be mounted, but it was the most convenient location on my machine.



The Carriage

The carriage is an assembly consisting of two sections of DOM tubing that ride on the bed bars, a flat top-plate and a universal block mounted to the center of the top-plate. The DOM tubing used to make the runners of the carriage does not have to be heavy. The only requirement is that it is thick enough to be threaded for the bolts that will hold the carriage together. Walls that are ¼" thick work well for this. The runners can be fitted with oilers and felt packing, but this isn't really necessary. I have found that if the bed bars are lubricated with a mixture of oil and lithium grease, they will remain nicely lubricated throughout the entire process of making a barrel. However, the bed bars should

be wiped clean and freshly lubricated before starting another barrel. The runners have a shallow flat milled on them so that the top-plate can be securely mounted to them. There are two holes drilled and tapped into each runner on the milled flats to accept the bolts that pass through the top-plate.

The top-plate is a ½" thick piece of steel. The main purpose of the plate is to provide a base for mounting the universal block. The plate should be drilled and tapped for four bolts that will secure the universal block to the center of the plate. When correctly mounted, the universal block should be very securely fastened and unable to be wiggled about even if the through-bolts that secure it happen to loosen a bit during a machining operation. To accomplish this, the threaded holes in the top-plate must be very accurately located. To achieve this level of precision, the top-plate must be drilled and tapped on a milling machine or at least a drill press that is equipped with a machining table with graduated dials. The top-plate also serves as the mounting platform for the half-nut, the rapid traverse chains and the rifling cylinder straps. However, the location of these threaded holes is not nearly as critical.

The universal block is a simple 2" square, steel block that has been bored to accept the tooling adapter and the forward bearing for the rifling cylinder. The center of the bored hole must lie precisely on the centerline of the barrel spindle. The bored hole for the tooling adapters is ¾" in diameter. The back end of the block is bored to accept a 1⅛" bearing for the rifling cylinder's forward axle. This socket for the bearing is only bored to a depth equal to half the width of the bearing. The bearing must be removed from the machine for the drilling and reaming operations and only sinking it into the universal block to half depth allows the bearing to be inserted and removed with finger pressure alone. The universal block is drilled and tapped through the top to accept a ½" bolt that is used as a set-screw for the tooling adapters.

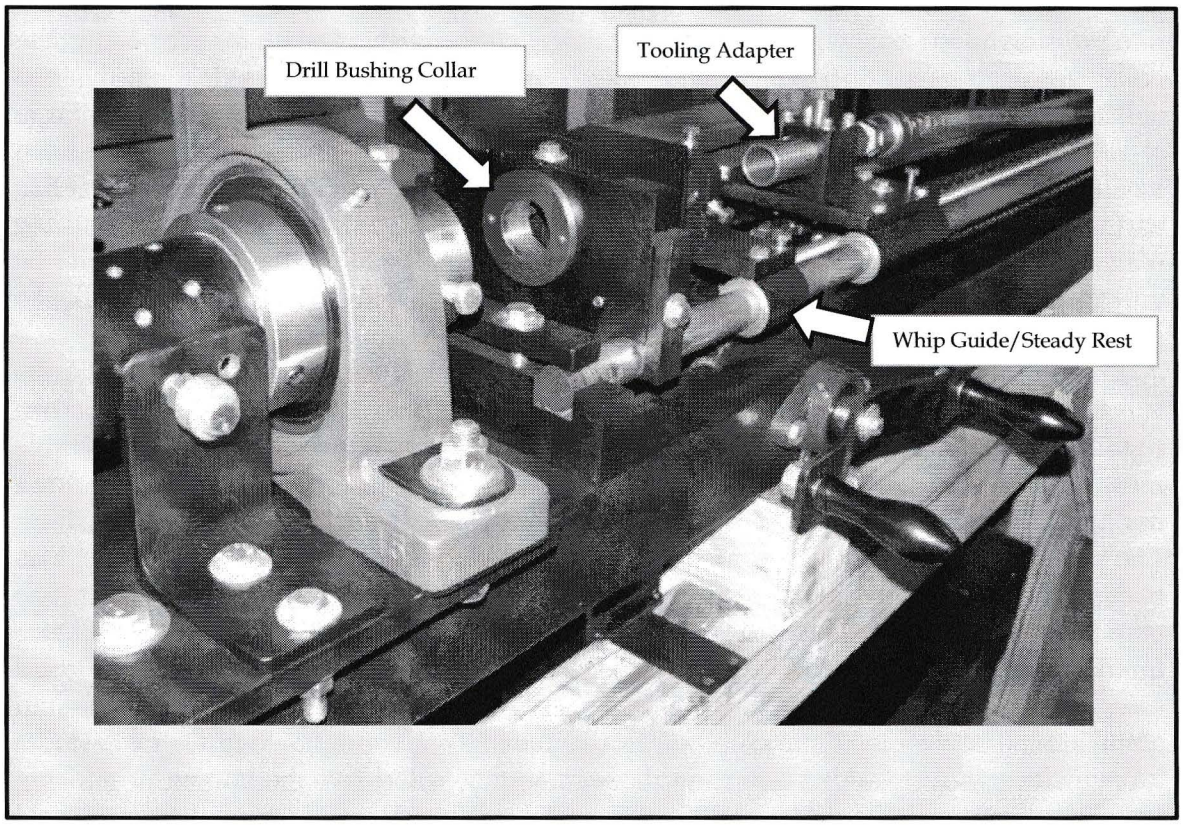
The rear carriage is a duplicate of the forward carriage except that it is only used to mount the rifling cylinder block. This block differs from the universal block in that it is only 1" wide and it is bored to accept a 1⅛" bearing to full depth. This bearing is mounted flush with the surface of the block because it never needs to be removed. Both the rear carriage and the forward carriage are threaded to accept the through-bolts for the rifling cylinder straps. The rifling cylinder straps are ½" square steel bars that tie the two carriages together, with the rifling cylinder mounted between them, during the rifling operation.

The Tooling Adapter(s)

The forward section of the tooling adapter is sized to accept the driver of the deep-hole drill. The diameter of the drill's driver is determined by the diameter of the drill itself. If you plan to use several different sizes of deep-hole drill, you may have to fabricate two or more adapters to accommodate the different sized drivers. The walls of the driver-holding portion of the tooling adapter should be about ¼" thick so they can be threaded to accept the set-screws that will hold the drill and reamer drivers in place during operation. The shank of the tooling adapter is ¾" in diameter with a ⅜" through-hole to allow cutting oil to flow through it. The shank should be a light press-fit into the bored hole in the universal block. If you have to lightly tap the adapter with a rubber mallet to get it in and out, that's about right. The top of the shank has a small flat milled on it to accept the ½" set-screw from the universal block. The rear end of the shank

features male threads to accept an appropriately sized hydraulic quick-disconnect with an O-ring boss seal. The hydraulic quick-disconnect has to be removed from the tooling adapter before the tooling adapter can be removed from the universal block, and the O-ring boss is the connector type that is best suited for this application.

A rubber O-ring is used to seal the interface between the rear surface of the tooling adapter's bore and the deep-hole drill driver. Drill driver diameters are standard sizes, so it is pretty simple to find an O-ring that will snugly fit the diameter of the adapter bore. This same O-ring is also used to seal off the reamer driver. The drivers of the deep-hole drills and reamers are locked into place with set-screws through the wall of the tooling adapter. Two screws are used for the drill driver and only one is needed for the reamer driver. Rearward hand pressure is used to keep the O-ring firmly in contact with the rear surfaces of the drivers while the set-screws are tightened. Believe it or not, this is all it takes to completely seal the connection. I have never had a single drop of oil leak out of one of my tooling adapters.



The Bushing Plate and Chip Box

The bushing plate is a rigid, vertical fixture that serves as the platform for the drill guide bushing. The stability of the bushing plate is determined by the width of its base. The wider the base, the more purchase the plate will have on the bed bars and the more stable it will be. My bushing plate is ¾" thick, which is actually none too wide. It is wide enough to seat firmly and it will remain stable throughout the drilling operation, but a 1" plate would probably be easier to set up and it would definitely be a bit more stable. The bushing plate is held fast to the bed bars by strap clamps. The inner surfaces of the strap clamps are shaped (relieved) so that they only make contact at the very ends of the

clamps. This is done to ensure that the clamps are actually clamped to the bed bars and not merely held fast to the sides of the bushing plate. In order for this arrangement to be effective, the lower contact point of the strap clamps must extend *below* the centerline of the bed bars. If they made contact with the bars at or above the centerline, you would be able to simple lift the bushing plate up and off the machine. This is obviously not what the clamps are supposed to do. It is tempting to put lock-washers on the bolts that secure the clamps to the bushing plate, but do not do this. I used to use lock-washers and they tended to skew the bushing plate out of alignment as they tightened down because their design prevents them from tightening down evenly. Since I removed the lock-washers, setting up the bushing plate has become far easier and it locks into position just as tightly as it did before.

The drill guide bushing does not interface directly with the bushing plate. Rather, there is a bushing collar that bolts to the bushing plate to do the job of actually holding the bushings. The collar is used so that the centerline of the bushing can be brought into perfect agreement with the centerline of the spindle. Two bolts secure the bushing collar into position on the bushing plate. The holes through the bushing plate for the bolts in the collar are drilled one drill size over the diameter of the bolts. This is done so that the collar can be moved a bit to bring it into alignment with the spindle. Once the collar is aligned with the spindle, it is locked to the bushing plate in a relatively permanent fashion by applying red Lock-tite to the bolts during final assembly. You do not need or want this part to move after it is aligned properly. The fit of the drill guide bushings in the bushing collars should be a firm slip-fit. As was the case with the fit of the tooling adapter in the universal block, if you have to lightly bump the guide bushings with a rubber mallet to get them to seat, that's about right.

The chip box attaches to the rear of the bushing plate with an arrangement of bolts and brackets. Exactly how it is attached doesn't really matter, just so long as it is oil-tight. The one and only purpose of the chip box is to catch and redirect the incredible mess that comes out of the bore during the drilling process. High-pressure oil flows through the deep-hole drill and out the tip to flush chips away from the cutting surface. The shank of the drill has a V-groove pressed into it so that the oil can flow backwards along the shank and out of the bore. After exiting the bore, the oil/chip slurry enters the chip box and is mechanically prevented from flowing any further along the shank. Once this happens, the only way for it to go is down and it is gravity fed back to the oil reservoir where a filtering system separates the chips from the oil before it goes back into circulation. The design of the chip box is not terribly important, as long as it can do its job. One design feature that I consider very important is to leave the bottom of the chip box completely open so that it can't be clogged by chips. Despite the name, you should think of it more as a chip chute than a chip box because the word "box" implies the presence of a proper bottom. The most troublesome aspect of the chip box is that it must form a seal around the shank of the drill to stop the flow of oil. I use common household sponge squeezed between the chip box and a gasket plate to form the seal. I have tried rubber, but it doesn't seem to squash down and form-fit the drill shank quite as tightly, so I went back to sponge. I designed my chip box to be a one-size-fits-all affair for barrels from 58 caliber to 4-bore, so there is quite a bit of airspace around the smaller drill shanks due to the size of the hole bored into the back of the box. If the hole was smaller, rubber gaskets would probably squeeze down and seal much better that they do on my

particular chip box. One problem associated with using sponge as a gasket material is the fact that the oil is laden with steel chips and the whole mess squirts out of the bore under pressure. Those sharp little high-velocity chips tend to eat away at the sponge and cause it to start leaking before the hole is finished. To counteract this, I use a piece of thin, hard plastic in front of the sponge to take the brunt of the chips' impact. This works very well and the plastic facers last for quite a few barrels before they need to be replaced. The sponge gaskets, however, are only good for one barrel and must be replaced for the next drilling operation.

The Whip Guide/Steady Rest

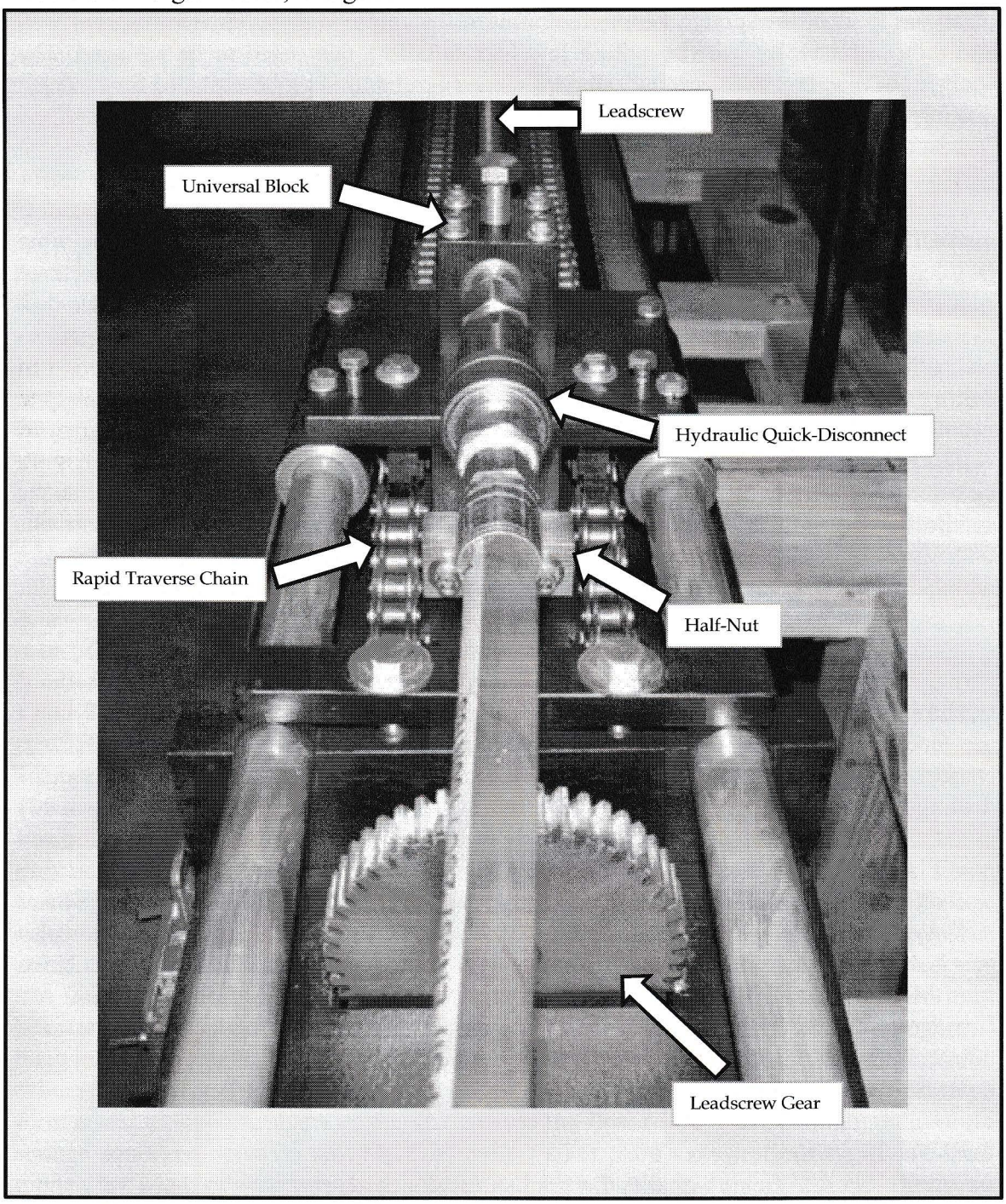
On some deep-hole drilling machines, namely those that spin the drill instead of the workpiece, the whip guide is a very important component of the machine. The whip guide prevents the shank of the deep-hole drill from bowing due to the effects of centrifugal force as the drill spins. It is absolutely impossible to balance a deep-hole drill to make it spin evenly because of the V-groove. This places the drill's center of gravity well off of the axial centerline, especially when the shank is carrying the extra weight of cutting oil. However, when a deep-hole drill is held stationary and the workpiece is spun instead, this out-of-balance condition does not arise and the whip guide is of questionable value. In fact, I don't use my whip guide at all during the drilling operation anymore because I found that it was doing absolutely nothing. Keep in mind, though, that the smallest drill I use measures .5700" and the shank is correspondingly stiff. Smaller drills with shanks that are more flexible than mine may very well benefit from the support of a whip guide even when the drill is not being spun.

The whip guide on my machine is very simply constructed. It is basically just a miniature copy of the steady rest for my lathe. This mini steady rest is mounted to a carriage that is identical to the other two carriages, except that it is considerably smaller. I was skeptical of the need for a whip guide when I was building my machine, so I didn't see much point in making it unnecessarily elaborate. As detailed above, my hunch was correct. However, the whip guide/steady rest does come in handy, just not during the drilling operation. I use the two lower screws to just barely kiss the pull-tubes of my reamers as they exit the bore so that they can't clunk into some part of the machine and possibly chip one of the flutes. During the rifling operation, I use all three of the screws to center and anchor a guide bushing that supports the pull-rod of the rifling cutter box as it leaves the bore. With the fine adjustments available with the screws, it can also precisely center the cutter box in the bore so that it slides right back in without knocking into the face of the barrel blank. You'll note that one of the bolts on my steady rest carriage protrudes from the top of the carriage. It is not a loose screw, or rather, it's not unintentionally loose. This screw goes all the way through the runner when snugged down and locks the steady rest in place on the bed bars.

Tool-Feeding Components

To cut a truly high-quality finished surface in steel, you have to use a very sharp tool and thrust that tool into the workpiece at a feed rate that is conducive to a smooth, chatter-free cut. The primary importance of using a positively driven feed system is that it allows the machinist to control the forces of thrust and torque that are placed on the tooling and transmitted to the workpiece and the machine. If the feed is too heavy, chatter

and vibration can cause a rough surface finish and reduce tool life (although a cutting speed that is too high will reduce tool life more drastically). The components of the feed system for the drilling and reaming operations are a leadscrew coupled with a half-nut, a reversible DC gearmotor, and gears to create an interface between the two.



Those are the basics of feeding a cutting tool for a mechanical cut. The proper feed rates and the methods of feed control are hard science for mechanical cuts. However, with a machine of this nature, the rifling cuts are more art than science. Certainly, the same principals apply, but the rifling cuts are made by hand and rely more heavily on feel

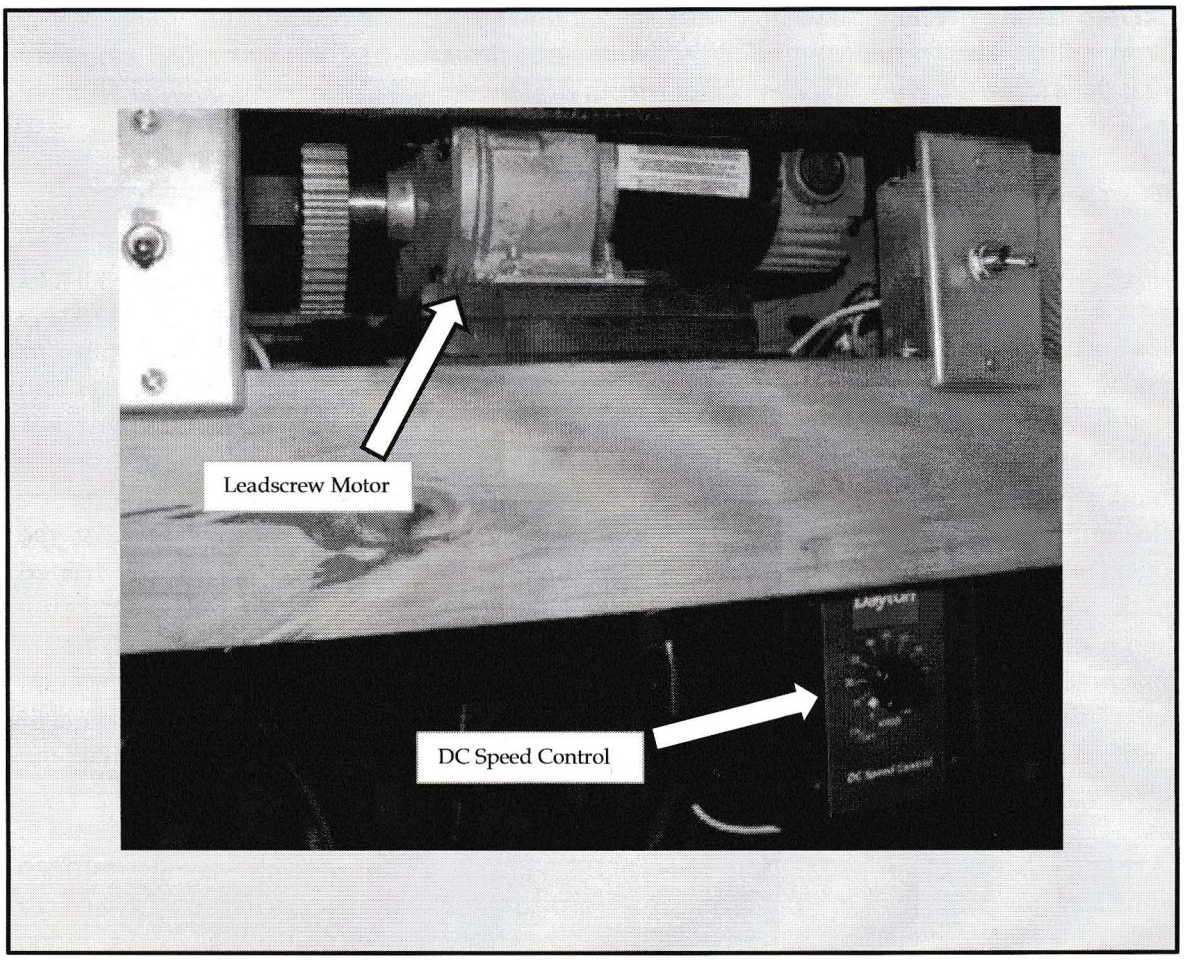
than cold calculation. The tool-feeding components associated with the rifling operation are a rapid traverse system and a twist-indexing system. And just to make a minor point for the sake of technical accuracy, these components actually control the *speed* of the hook cutter. The feed is controlled by the components of the rifling cutter box assembly that determine the hook cutter's height (depth of cut). Nonetheless, whether you call them tool-feeding or tool-speeding, we will be looking at these components in this section.

The Leadscrew and Half-Nut

I don't know who invented the inclined plane as a useful tool to lift big loads with little force, but he was a pretty clever fellow. And the guy who came up with the idea of wrapping that slanted surface around a cylinder was an absolute genius. This is what a leadscrew is– an inclined plane wrapped around a rotating cylinder for the purpose of pushing a load. The typical style of leadscrew associated with machine tool work is one that is cut with centralizing acme threads. There are two primary reasons why this type of thread is used on machine tools. First of all, this type of thread is almost impossible to bind, even when the threads are contaminated with chips. But the most important reason lies in the fact that it is very easy to engage a half-nut on a spinning screw with this type of thread cut. When a workpiece is threaded on a lathe, the half-nut must be disengaged at the end of each pass and then re-engaged to start the next pass. This makes centralizing acme threads a very important feature of lathe design. However, the half-nut of a barrel machine is only engaged and disengaged while the leadscrew is stationary, and common UNC threads work very well under these conditions. Centralizing acme threads will certainly perform with distinction on a barrel machine's leadscrew, but they are not the absolute necessity in this application that they are on other types of machine tools.

My leadscrew is a length of high-grade all-thread with a ¾-10 UNC thread pitch. A higher grade of all-thread was chosen for strength and, especially, smooth surface finish. A lower grade of all-thread would be strong enough, but the surface finish is rough enough that the leadscrew would have to be lapped before installation to avoid undue wear on the half-nut. The ends of the leadscrew are turned for a light press-fit into single-row ball-bearings. One end of the leadscrew is mounted into the middle bed bar mounting block by seating one of the bearings into it. The other end of the leadscrew is similarly mounted in its own, smaller block that fits easily between the bed bars and rapid-traverse chains. Small pillow-block bearings could also be used to mount the leadscrew, but that option doesn't allow much flexibility in design. By making my own mounting blocks, I was able to set the leadscrew at the height above the machine bed that worked best for the overall design of the machine; not the height that happened to be available with commercially-made pillow-block bearings. The business end of the leadscrew is fitted with a spur gear. The fit of this gear on the leadscrew should be a tight force-fit to bind the two pieces together as a single unit. Actually, in the case of my machine, there are three pieces bound tightly together. The largest bearing race size for bearings that will fit into the bed bar mounting block is ½". The corresponding journals on the leadscrew must also be turned to ½". However, to obtain the arrangement between the leadscrew and gearmotor that I wanted (motor mounted under the bed), I had to use gears with a 4" pitch diameter. The smallest bore size I could find in 4" gears was ⅝". So after fitting the leadscrew into the bearing and the whole assembly into the bed bar mounting block, I had

to make a bushing for the gear. I used my bench vise to press the bushing into the gear and then used a rubber mallet to firmly seat the gear/bushing unit onto the leadscrew.



The leadscrew is driven by a reversible DC gearmotor. My primary concern when selecting a gearmotor was ensuring that the motor would fit under the bed of my machine. I wanted the motor placed in this position so that it would not be in the way of the rifling cylinder after the drilling and reaming operations were complete. I obtained schematic drawings of several brands and types of suitable gearmotors on the internet to check the physical dimensions for fit. The gearmotor that was literally the best fit for my machine was a Dayton. As mentioned when discussing the horsepower requirements of the spindle motor, the thrust and torque generated by deep-hole drills is very low due to the design of the drill and the fine feeds used for this type of drilling. Most of the spindle motor's horsepower goes into overcoming the friction and inertia associated with rotating the spindle itself at high speed. However, the leadscrew turns very slowly so the leadscrew motor only has to contend with the forces generated by the drill. My leadscrew motor is rated at 1/15hp with .84 Amps at 90V DC and this has proven to be plenty of power for drilling holes up to .8100" in diameter. The leadscrew motor is equipped with a DC variable speed control to set the feed rate for the diameter of drill or reamer being used. The speed control came as a separate unit and had to be wired into the motor circuit. The speed rating that the motor needs to have is determined by the feed rate the reamer(s) will require for the speed of cut being made. Since I was using a 1:1 gear ratio

between the motor and the leadscrew because of the mounting arrangement I had chosen for my motor, I chose a gearmotor with a speed rating of 6.5 rpm. Because the pitch of the threads on the leadscrew is 10, this gives me a maximum feed rate of .65" per minute. If you're going to be making small-caliber barrels with a high cutting speed, you will probably want a gearmotor that is faster than mine. You may not require a faster feed than that for drilling, but you may very well want a faster feed for reaming.

The half-nut is made of brass. Brass is used instead of steel so that the half-nut will be sacrificial to the leadscrew. Fabrication of the half-nut is accomplished by simply drilling and tapping an appropriately sized piece of brass to accept the threads of the leadscrew. The half-nut (although I suppose at this point it's really a whole-nut) is then drilled in two places for through-bolts that will secure it in position under the carriage. An end-mill is then used to lengthen the holes into slots about twice the length of the diameter of the screws that will be used. The slots allow the half-nut to be slid back and forth to engage or disengage from the leadscrew. After the slots are milled, the half-nut can be split with a hacksaw (now it really is a half-nut). The hacksaw removes enough material from the central portion of the half-nut to allow it to close tightly around the leadscrew. The rough-cut edges are filed smooth. I also like to file a slight bevel on the edge of the threads to make sure that there are no burrs or sharp corners that can be damaged and prevent the half-nut from locking tightly around the leadscrew. The half-nut is mounted to the underside of the carriage by way of a simple mounting plate that is bolted to the carriage. The plate is drilled and tapped for the half-nut screws and a small cut-out is made to allow the leadscrew to pass through it.

Rapid-Traverse System

The rapid-traverse system is used to quickly and efficiently reposition the carriage during machine setup. Of greater importance, it is also used to power the cut during the rifling operation. The rifling is cut .0001" at a time, so there is no need for mechanical power for this operation. The simplest, most expedient rapid-traverse system runs on good old-fashioned elbow grease and nothing else. While the cuts being made are relatively light, they are still cuts being made in steel, so mechanical advantage is important. The crank handle of my machine is fairly large with the opposing handles mounted 12" apart, measured center-to-center. The handles themselves are free-spinning and are equipped with threaded studs that go through the crank and are fixed with nuts and lock-washers. The crank handle shares its axle with the drive sprockets of the system.

The drive sprocket axle is held in position on the machine bed by 2-bolt flange bearings that are mounted on the sides of the machine bed. While these bearings are not required to run at high speed, they will get quite a workout over the course of making several barrels and should be equipped with grease fittings so that they may be lubricated periodically. The drive sprockets are heavy-duty sprockets intended for farm use. Each sprocket has two set-screws to lock it firmly to the axle. While the rifling operation doesn't require the strength of dual drive sprockets, I fit my machine with twin sprockets because there wasn't enough height between the machine bed and the carriage to allow both the leadscrew and the drive chain to be mounted centrally (one atop the other) under the carriage. The redundancy of having a drive sprocket on each side precludes the possibility that the carriage could be put in a bind by being pulled by a single, off-center

sprocket. If you can mount your rapid-traverse system on the centerline of your machine bed for an even pull, there is really no reason to use more than one drive sprocket.

The idler sprockets are also heavy-duty farm grade sprockets. They come equipped with their own integral, sealed bearings. The idler sprocket axle is a length of common all-thread. A nut and lock-washer on each end of the axle secure it to the machine bed. The idler sprockets are adjusted laterally and locked in place by pairs of opposing jam-nuts, one on each side of each sprocket. The drive chains, like the sprockets, are heavy-duty farm grade equipment. Tension of the chains is adjusted by moving the drive sprocket axle (the through-holes for the axle in the bed are oversized to allow this). Notice, however, that my chains are not stretched banjo-string tight. I intentionally left the drive chains a bit slack so that their weight would rest on the machine bed instead of on the bed bars. The bed bars actually sag a few thousandths of an inch under their own weight. In addition to their own weight, the bed bars must also carry the carriage and all of the rifling tooling. During the rifling operation, the rifling cutter box is guided by the bore of the barrel blank, not the bed bars. But I still didn't like the idea of further burdening the bed bars with extra, completely unnecessary weight. Especially when that weight is doubled in magnitude by *twin* drive chains. The rotation of the rifling cutter box is entirely dependent upon the rifling cylinder and has nothing to do with the drive chains, so there are no consequences for leaving the chains slightly slack so that their weight will rest on the machine bed.

DC Speed Control and Switches

Since the gearmotor that I chose for the leadscrew was a Dayton, I obtained my DC speed control from the same source to ensure complete compatibility. The speed control is rated for 1/50 to 1/6hp and 90V DC. It is minimum/maximum adjustable, meaning that the gearmotor can be run from top speed all the way down to zero. The speed adjustment is made with a dial and calibrated indexing marks that are labeled in 10% increments of nameplate speed. The indexing marks on the speed control are very close to their rated value (10%, 20%, etc.) but they are not quite perfect, especially on the low end of the scale. After assembly of my machine was complete, I engaged the half-nut with the leadscrew and marked the starting position of the carriage on the bed bars by wrapping a piece of tape around one of the bars tight against the carriage runner. I then ran the gearmotor for a timed five minutes at each whole increment of speed setting and measured the actual travel of the carriage with a dial caliper. This figure was then divided by five to get the actual feed per minute for each percentage setting of the speed control. This is a much more accurate way of determining feed rate than simply calculating the feed as a percentage of maximum gearmotor speed. Running the carriage for five minutes instead of only one minute reduced the effect of any inaccuracies in my measurements (of either distance or time) by a factor of five.

The speed control also doubles as an on/off switch because it positively clicks off just past the 0% mark. However, the speed control cannot reverse the direction of the gearmotor to make the switch from drilling to reaming. To change directions, I installed a two-position (on/on), 20 Amp, 125V AC toggle switch in the circuit between the speed control and the gearmotor. Two sets of leads run from the switch to the motor leads to reverse the polarity. Note that my switch is not rated for DC current. DC will heat switch contacts far more than AC will and can weld the contacts together if the DC amperage is

too high. The only seemingly reliable information I have been able to find for using AC rated switches for DC suggests that a 20 Amp, 125V AC switch is only good for .75 Amps at 115V DC. So even though my gearmotor is rated for only .84 full load Amps at 90V DC, I would not trust a switch that is rated for only 10 Amps of AC. Also, note carefully what I said above about using the speed control as the on/off switch for the DC gearmotor. The AC switch may not open far enough to break the arc of direct current at 90V because the arc produced by direct current is much harder to break than the arc produced by alternating current. That's why DC is used for welding applications. However, the 20 Amp, 125V AC switch will indeed hold up to the .84 Amps of direct current as long as the switch is used only to reverse polarity of the circuit *after* the circuit is dead and current stops flowing. This is why a two-position switch will suffice. A three-position (on/off/on) switch with an AC rating may lead to problems if it is used as the actual on/off switch in a 90V DC circuit instead of being used only for reversing the flow of current through the circuit.

Fortunately, there are no special considerations when choosing the spindle and oil pump switches. The motors used to power these components are standard farm-duty AC motors. As such, standard AC switches will work just fine. Again, I chose switches rated for 20 Amps and 125V AC. They are standard two-position (on/off) toggle switches that can be purchased at the local hardware store. The wiring, on the machine and in the shop's circuits, should also be rated for at least 20 Amps and the circuits will need to be grounded. If your shop is in an old building with ungrounded wiring (two holes in the outlets instead of three), you will need to install at least two grounded circuits in your shop. You will need at least two because the total electrical load demanded by the machine when all three motors are running will greatly exceed 20 Amps, so they can't all run on the same circuit.

Component Assembly and Alignment

Unless you're using the ways of an old long-bed lathe as the bed of your machine, you will face some pretty serious challenges when trying to align the components of your machine to the required level of accuracy. No matter what material you choose to use as the machine bed, it is not likely to be nearly as straight as the proverbial arrow. This does not constitute an insurmountable problem, but you do need to be aware that there *is* going to be a problem in this regard. I chose to use a piece of 8" structural channel as the bed of my machine. The reasons for this choice were simple: it was readily available, relatively inexpensive and it provided a wide, ready-made surface on which to mount the machine components. There are certainly other suitable choices for the bed of a machine such as this, so feel free to try something else if you'd prefer. But no matter what materials you choose for fabricating the bed of your machine, you will still face the same types of alignment issues that I did. The following section summarizes how I managed to build a well-aligned machine on a less than ideal foundation.

Actually, that last statement isn't entirely accurate. While the structural channel I used for the machine bed was indeed slightly crooked in both directions, the true foundation of the machine, the bench, was just about perfect. When I built the bench for the machine, I took my time and made sure that it was completely solid and, just as importantly, that the top was *perfectly* level in both directions for the full length of the bench. The only practical way to achieve vertical alignment of the various machine

components is by using the same precision level that you use to level the bed of your lathe. But in order for this technique to work, the top of the bench must first be trued with the same precision level. *Do not skip this step*. If you try to build a barrel machine on a bench top that's twisted or out-of-level, you will be setting yourself up for certain frustration and probable failure.

Establishing the Centerline

The centerline of the machine will serve as the reference point from which the placement of every component will be determined. For this reason, the centerline must be marked as accurately as possible. But before marking anything, it is a good idea to sight along the bed of the machine to get a feel for how straight it is. The idea is to place the centerline of the machine components in the location that will allow the most lateral leeway for component placement. For example, if the bed is bowed right or left, it is a good idea to offset the centerline a bit in the direction of the convex portion of the bend. This will give you a little more room to mount the components that are placed in the middle of the machine than you would otherwise have. To do this, stretch a string along the side of the machine across the bow (on the concave side). Measure the maximum distance of the string from the side of the bed, and then divide this number by two. After marking the exact center of the bed width on each end, measure towards the bow (the convex side) by this amount and make another mark. By establishing the centerline from these two adjusted marks, you will be splitting the difference of the bow and allowing the maximum possible mounting surface for all of the components.

After marking the machine centerline on each end, stretch a string between the marks. This will be the actual centerline of the machine. When stretching the string, you do not want the center of the string on the marks. Place the string so that *one side* of the string aligns with the marks. Subsequent marks along the length of the bed will be made from the side of the string and will not line up with the end marks unless these marks also align with the side of the string. If the bed lies perfectly flat or bows down in the middle, you're all set to mark the centerline. If, however, the bed bows up, you will need to place shims under each end of the string to lift it off of the bed. The only way to ensure that the string is perfectly straight is to ensure that it does not make contact with the bed anywhere except at the ends.

Before going any further, use a four-foot level to level the string by shimming under the low end of the bed. Note that you shim under the *machine bed*, not the string. Remember that you will need to establish the centerline of the machine on both the horizontal and vertical axes. Establishing vertical alignment will be all but impossible if the centerline from which all components are referenced is not level. Once the string is stretched in place and leveled, you can now use it to accurately locate the centerline along the entire length of the bed. Place an accurate square on the bed of the machine and slide it up to the string until it just barely touches the string *without displacing it to the side*. Use a sharp scribe to put a mark on the bed at the base of the square. It is a good idea to use a square with a built-in level so that you can make sure that it is not canted. Canting will put the centerline marks off by a bit. There is no reason to scribe the centerline the full length of the bed. Determine where the relevant components (spindle base plate, leadscrew bearings and bed bar mounting blocks) will sit beforehand and then just mark the centerline in these locations.

While the string is stretched across the bed of the machine, measure the distance from the *bottom* of the string to the bed at every location where a machine component will be placed and write these measurements down. A steel machinist's rule that allows you to measure to the nearest hundredth of an inch will suffice. When fabricating the components, adjustments can be made for the difference in required height to alleviate the need for shimming material later. For example, the bed of my machine bows down slightly in the center. After milling the slots in the bed bar mounting blocks where the bed bars would eventually sit, I milled a bit off of the bottoms of the two end blocks while leaving the center block full height. The amount to mill off of each one was determined by measuring to the string during this step. The centerline of the machine has now been established. By accurately marking the centerline of each individual component and aligning these marks with the centerline marks on the bed, the alignment of the entire machine should be very close to perfect at the time of assembly with just a bit of tweaking necessary afterward.

Aligning the Bed Bars

If the centerline is accurately marked on the bed and the centers of the bed bar mounting blocks are accurately placed on this line, then the horizontal alignment of the bars will take care of itself (at least for now). The task that remains is to ensure that the bars are level along the length of the machine (aligned with the vertical axis) and situated at the exact same height from side to side. This last bit is extremely important. If the bed bars aren't at the same height, the universal block on the carriage will be tipped as the carriage travels and this tipping will move the driver of the cutting tool off of the centerline of the spindle.

Aligning each individual bar with the vertical axis seems pretty simple and straightforward– just put the precision level on the bar and shim as necessary until it is level, right? The rub is that the bars sag ever so slightly under their own weight. They look nice and straight and I thought they were until I put the precision level on them. It was only then that I realized things are not quite as they appear to be. Luckily, there is an easy cure for this particular ailment. Place a four-foot level (the kind with the V-groove on one side that's designed to sit on round things) on one of the bed bars and then place the precision level on top of this. A four-foot level is light enough and stiff enough to remain straight without sagging under its own weight, thus providing a true surface for the precision level. The four-foot level must be placed precisely between the mounting blocks or the slight bow of the bar will cant the level slightly and give a false reading. It should also go without saying that the four-foot level needs to be in very good (straight) condition, so don't use the one that's been banging about in the bed of your pick-up truck for the last five years. *Now* alignment is as simple as placing shims under the bars until they are level.

The next step is to ensure that the tops of the two bed bars are at precisely the same height. To do this, place the precision level so that it spans across the bars (perpendicular to the machine bed). If your bars are too far apart for the precision level to reach them both, you can again employ the longer level under the precision level. Shim under the low bar to bring it up to the same height as the other one. Remember that you have already leveled each individual bar along the other axis, so you will have to shim under the bar by the same amount at each mounting block to keep it level. Theoretically,

this will maintain the low bar in a longitudinally level condition as it is brought up to match its cohort, but it is a very good idea to double-check after shimming just to be sure.

One more thought on this before we move on. The runners for the carriages and the whip guide/steady rest will be on the bed bars during this process. If your bed bar mounting blocks aren't far enough apart to fit a four-foot level between them and the carriage and steady rest runners, you will have to use a two-foot level or other suitable stiff, *straight* implement to level the bed bars on the longitudinal axis. A four-foot level was the simplest, handiest straight edge that I had available and it did fit between the mounting blocks and runners on my machine, so that it what I used. You may have to employ another tool to accomplish the same thing if your bed bar mounting blocks are too close together.

Aligning the Spindle

Much like the bed bar mounting blocks, marking an accurate centerline on the spindle base plate will go a long way towards getting it aligned on the machine centerline. Up to this point, we have been using a working centerline to align the components of the machine. That is all finished after this point. The centerline of the spindle will be *the* centerline of the entire machine. After initially aligning the spindle with the bed bars on the working centerline and leveling it, all other components of the machine must be brought into agreement with the spindle, not vice versa.

Vertical alignment of the spindle is accomplished by using the precision level and shimming as necessary to level it, just like the bed bars. Unlike the bed bars, there is no need to try to level the spindle bearings across the bed of the machine. The reason for this is that the spindle bearings, unlike the carriage that rides along the bed bars, are fixed in position. Once they are shimmed to level the spindle longitudinally, it doesn't matter if they are canted a bit one way or the other. However, canting of the spindle bearings will necessitate a bit of lateral adjustment of the spindle's position to bring it into precise alignment with the bed bars.

Aligning the spindle with the bed bars, both horizontally and vertically, presents a bit of a problem for the home-shop machinist who doesn't have a bunch of lasers, collimators and other assorted digital gizmos and doo-dads lying about to make his life easy. I considered several different techniques to crack this particular nut, each of which had its merits. What follows is a synopsis of the method that I finally settled on as being the most practical *accurate* way to align the major components of my machine.

The trick to aligning the axis of the spindle with the bed bars is to first make the axis visible in some way. The method that I chose to make the spindle axis visible was to fabricate and install a set of simple, yet effective, alignment lenses on the spindle. To do this, first measure the bore diameter of the spindle to the nearest thousandth of an inch. Then set a pair of spring calipers to exactly one-half this distance (the radius of the bore). Set the point of one leg of the calipers onto a sheet of thin, clear plastic and *lightly* poke it through. You want the through-hole to be as small as possible. Use the point of the other leg of the calipers to scribe a circle into the plastic. Scribe a second circle into the plastic that is slightly smaller in diameter than the outside diameter of the spindle. Now cut the plastic along the circumference of the second, larger circle. Repeat this process to make a second lens identical to the first (actually, you'll draw both small circles before adjusting the calipers). Now, align the lenses with the bore of the spindle and tape them into place.

If you scribed the inner circles to *exactly* match the bore diameter of the spindle, aligning them precisely will be a snap. If you got them a few thousandths of an inch too large or too small, throw the lenses away and make another set. Do make sure that you get the lenses precisely centered because the success or failure of this whole operation depends on it. The clear plastic of the lenses allows a full view of the rest of the machine through the spindle and the exact centerline of the spindle is marked by the holes in the centers of the scribed circles. Now we just need a point of reference with which to align the spindle centerline.

Before we can place a point of reference on the bed bars with which to compare the axis of the spindle, we first have to assemble the carriages. Install the top-plates onto the carriage runners to assemble both carriages. Make sure that the centerline of each top-plate is clearly marked. At this point in the process, you know (or at least *should* know) the height of the various components above the machine bed. More to the point, you know the height of the spindle centerline and the height of the upper surface of the top-plates of the carriages. Determine the difference between these two heights and write it down. Next, tightly wrap a block of some material (steel, wood, etc.) with a piece of plain white paper. The exact size and shape of the block aren't important, but the corners do need to be square. Carefully and accurately draw a thin horizontal line on the paper. The height of this line above the bottom of the block will be the same as the difference between the height of the barrel spindle centerline and the carriage top-plate. Now draw a thin vertical line on the paper somewhere near the center of the block. Place the block on the carriage and align the vertical mark with the centerline on the top-plate. The intersection of the two lines drawn on the paper represents, at least in theory, the exact centerline of the spindle and thus the exact centerline of the entire machine– X marks the spot. In practice, it will only represent the centerline if you've gotten all of the steps prior to this just right. That's what we're about to check.

Now that you have a point of reference, you should be able to look through the alignment lenses on the spindle and see that, when the two punch marks in the lens centers are aligned, they will also be aligned with the intersection of the lines on the block. The easiest way to align the lens centers with your eye is to treat them as a set of open sights on a rifle. The rear sight is the lens on the outboard side of the spindle. If you bring your eye very close to the lens, you will be able to look right through the tiny center hole just like a tang-mounted peep sight. It will then be a very simple matter to tell whether or not the hole in the other lens, the front sight, is aligned with the target because the forward hole will appear as a tiny black dot when looking at it through the dark interior of the spindle bore. Move the carriage incrementally back and forth and then sight through the lenses again. Even better, have a helpful friend available at this point who can slide the carriage back and forth while you sight. Take careful note of any apparent change in the relationship between the front sight and the target (the intersection of the lines on the paper). If the target appears to get higher as the carriage moves farther away from the spindle, the front bearing of the spindle needs to be shimmed to increase its height. If the target appears to get lower, the rear bearing needs to be shimmed. And, of course, if the target drifts left or right, the spindle position will need to be adjusted accordingly. The lateral positioning of the bed bar mounting blocks may also need to be adjusted, especially if your machine requires the installation of three blocks instead of two. If your machine has a second rear carriage to carry the far end of a rifling spindle,

simply repeat this process with the paper-wrapped block sitting on the rear carriage. The most important thing to realize is this: your adjustments are not complete until the apparent position of the target at *all* points along the bed bars is absolutely fixed in relation to the sights.

Note that I've been talking about the apparent position of the target. This is because the spindle centerline does not have to sit precisely at the calculated height that you had intended. From this point forward, everything else will be made to match the spindle centerline height, no matter what height that happens to be. So the intersection of the lines you drew on the paper may be a whisker above or below the spindle axis. This doesn't matter as long as the relative position of the target in relation to the sights remains constant. If, however, the horizontal line is more than the merest whisker too high or low, it would be best to erase it and draw another to make sighting easier. There is one final alignment check that can be made with this setup. If you back away from the rear lens by a few feet, then *both* of the sights will appear as tiny black dots. It is more difficult to get your head in just the right position (and keep it there, nice and still) to align the sights this way, but it will also give you a more accurate look at the alignment of your machine.

Use both methods of sighting (near and far) and double-check your work. Take a break to give your eyes a rest, then come back to check and double-check again. Fiddle and piddle, fuss and fidget until everything is just right. Then check again one last time to be sure. The alignment of this type of machine needs to be, and deserves to be, as close to perfect as you can possibly get it. I spent the better part of a full day on this spindle alignment procedure before I was satisfied that it was as good as I was going to get it. When I was finished, the sights, even when viewed from afar as two tiny dots, never strayed outside the thickness of the pencil lines on the paper no matter how far from the spindle the carriage happened to be. In an effort to gauge the accuracy of my alignment, I measured the thickness of the pencil lines. They measured right at .030" wide. So my 10½-foot long machine is aligned to within .030" over its full length on both the horizontal and vertical axes. That equates to a bit less than .003" per foot. Not too shabby for a make-shift alignment technique and certainly precise enough for drilling a hole with a self-centering cutting edge that is nearly four feet in front of the carriage.

Aligning the Remaining Components

Now that the spindle axis had been permanently established, the tool-holding components of the machine can be precisely aligned on this centerline. The components that need to be precisely aligned with the spindle are the drill guide bushing collar, the universal block and the rifling cylinder block. The first order of business is to accurately mark the location of the centerline on the critical components to ensure that the holes bored through them are properly placed. Measuring from reference points on these pieces to determine the location of the centerline is not accurate enough. Fortunately, now that the spindle and bed bars are locked into position, the locations of the penetrations can be marked with absolute precision without measuring anything.

The easiest and most accurate way to mark the tool-holding components for boring is to use the spindle to hold a marking device precisely on the centerline. This is done by using a stiff, round bar of steel to make a center-punch. The bar should be at least three feet long so that it will extend all the way through the spindle and out over the

machine bed far enough to reach the components that need to be marked. Center the bar in the lathe using a four-jaw chuck. Cut a light journal surface on the circumference of the bar to create a smooth, accurate surface for a dial indicator to contact. Then turn a tapered point onto one end of the bar. Mount the bar in the barrel spindle and use a pair of indicators on the journals to *precisely* center the point on the axis of the spindle. Take your time and make sure that it is dialed in perfectly. Position the point of the bar so that it will just kiss the bushing plate when it is placed into its proper place on the machine.

Mount the bushing plate on the bed bars and snug it into position. Make sure that it is perfectly perpendicular to the bed bars so that the location of the bored hole will be precisely aligned with the spindle axis. Also make sure that it is lightly contacting the point of the alignment bar. Now all it takes is a light tap on the back of the bushing plate with a rubber mallet to mark the location of the spindle centerline. Don't hit it too hard– there are still two more components to be marked and you don't want to dull the point. Remove the bushing plate from the machine and set it aside.

Now bolt the universal block into place on the carriage. The through-holes in the block for the bolts that secure it to the carriage top-plate should be drilled to the same size as the major diameter of the bolts. This will ensure minimal room for error in positioning the block both for marking the spindle centerline and for permanent installation after the hole is bored through it. Slide the carriage forward until the universal block barely touches the point of the alignment bar and lightly rap it with the rubber mallet to mark the spindle centerline. Remove the universal block and set it aside as well.

If your machine has a rear carriage for carrying the back of a rifling cylinder, you will also need to mark the spindle centerline on the rifling cylinder block. Obviously, the rear carriage can't be slid forward far enough the make contact with the alignment bar because there is a bed bar mounting block and leadscrew gear in the way. The only option is to mount the rifling cylinder block on the forward carriage in place of the universal block so that it can be marked the same way the other components were. This should make it pretty clear that all of the bolt-holes, both the through-holes in the blocks and the threaded holes in the carriage top-plates, need to be very accurately located so that this procedure will work. After sliding the carriage forward once again and marking the rifling cylinder block with the alignment bar, the rifling cylinder block can be removed from the machine and all three pieces can be bored out to the required inside diameter.

A similar technique can be used for final assembly of the components. Once the bushing plate is bored out for the drill guide bushing, then drilled and tapped to accept the bushing collar's screws, these components can be installed on the machine for final assembly. Start by making a new alignment bar. This bar must have a journal surface turned onto it that is the correct diameter for a very light press-fit into the drill guide bushing. Once the bar is turned, install it in the spindle and *very precisely* align the journal with the centerline of the spindle using dial indicators. The relationship between the spindle and the drill guide bushing is *the single most critical interface of the entire machine*, so be very careful in making absolutely certain that the journal is *perfectly* centered before proceeding. Once the alignment bar is centered, press the drill guide bushing onto it. Hand pressure should suffice to fit the two pieces together. If you think you need a hammer to get the job done, the journal surface is too large in diameter and it needs to be shaved a bit. Once this is done, fit the bushing collar onto the drill guide

bushing. Now carefully install the bushing plate on the bed bars and lock it into position. It should be in firm contact with the bushing collar. The through-holes in the bushing plate should be slightly larger than the through-bolts that will fasten the bushing collar to the bushing plate. This ensures that the bolts will not slide the collar out of alignment when they are snugged down. Now that everything is in place, rotate the spindle until the through-holes in the bushing plate are aligned with the threaded holes in the bushing collar. Slather the through-bolts with red Lock-tite and install them. Tighten them down very firmly to ensure that the bushing collar can't move– ever. Now very carefully loosen the spindle cat-head bolts and slowly slide the alignment bar backwards until it clears the bushing plate assembly. Remove the entire assembly from the machine and set it somewhere safe to allow the Lock-tite time to cure. Congratulations, you just completed the most critical phase of the machine's construction. Breathe a sigh of relief and get ready for the next step.

The same basic procedure will be used to align the universal block during assembly. The difference is that this time another actual component of the machine will be used to do the alignment. When fabricating the tooling adapter that will hold the drivers of the deep-hole drill and reamer, fabricate it on the end of a bar long enough to be used as an alignment bar in the spindle of the barrel machine. The rear-end of the adapter must be located at the end of the bar so that it can slip into the universal block. You can, and should, go ahead and complete all of the lathe work that needs to be completed on that end of the adapter, including drilling the oil hole and threading the tenon for the hydraulic quick-disconnect, before removing the bar from the lathe. Center the tooling adapter (and alignment bar) on the axis of the spindle as before with the other alignment bars. Then slide the universal block into position on the adapter. The fit of the adapter into the universal block should be a bit more snug than the fit of the drill guide bushing into the bushing collar to allow for a bit of wear on the components. You may need to tap the universal block into position with a rubber mallet. Once it is in position, orient the universal block top-side-up by rotating the spindle and slide the carriage under it. If you accurately located and bored the hole in the universal block, it should lightly scrape the top-plate of the carriage as it is slid into position. After slathering the threads of the through-bolts with red Lock-tite, install them and firmly anchor the universal block into position on the carriage. Slide the carriage assembly out from under the alignment bar and off of the tooling adapter. The tooling adapter can now be cut off of the bar and finished in the lathe.

There is no way to use an alignment bar to install the rifling cylinder block on the rear carriage. If you tried it with a very long bar, the bar would sag so far under its own weight and be so floppy and wiggly that the procedure would not be worth the effort. This is where accurate drill work when making the penetrations in the block and the carriage top-plate will pay dividends. The tight through-holes in the rifling cylinder block will also ensure that there is absolute minimum play between the bolts and the block. This will be the only alignment you get with the rear carriage. Fortunately, this assembly is the least critical in terms of alignment because it does absolutely nothing during the drilling and reaming operations. Sure, it holds the rear end of the rifling cylinder and this needs to be kept in line with everything else. But by the time you begin rifling, the bore of the barrel is already established and the rifling operation can't influence its concentricity for better or worse. So if the tail end of the rifling cylinder is a few

thousandths of an inch out of alignment with everything else, I assure you that the sun will still come up tomorrow.

The last component that needs to be aligned is the leadscrew. One end of the leadscrew is mounted in a bed bar mounting block and that end is now permanently fixed in position. To align the other end with the bed bars, the carriage that rides on the bed bars must be employed. Position the carriage as close to the fixed end of the leadscrew as you can and lock the half-nut into position on the leadscrew. Remember that you will have to reach between the carriage and the bed bar mounting block to tighten the bolts that lock the half-nut into position, so leave some room for your fingers. The leadscrew motor can be used to run the carriage forward on the leadscrew, but this will take forever because no matter what feed rate you intend to use, it won't be more than a couple inches per minute. It's best to leave installation of the leadscrew motor until after the leadscrew is aligned. With no gearmotor or its associated spur gear in the way, the leadscrew gear can be quickly turned by hand to zip the carriage to the other end of the leadscrew in no time flat. Once the carriage has reached the far end of the leadscrew, the leadscrew mounting block can be bolted into place. This is also the time to place shims under the leadscrew mounting block, if necessary. Both ends of the leadscrew are now fixed in position and the entire leadscrew assembly is perfectly aligned with the bed bars (and everything else).

Now that the major components of the machine are assembled and aligned into perfect harmony with one another, the rest of the machine's components can be assembled at your leisure. The hardest part is now officially over and you are almost ready to start making rifle barrels from scratch with your very own machine that you built with your very own hands. If you're not beginning to get excited at this point, you should probably just stop right here and go play golf.

CHAPTER 5: The High-Pressure Oil System

High-pressure oil is injected into the barrel blank at the interface of the workpiece and cutting edge during the drilling and reaming operations for three purposes. The first job the oil has to do is to provide lubrication so that the cutting action will be smooth and chatter free. It will do no good to cut a hole through the barrel blank if the finished bore is so rough and uneven that it is not suitable for the intended purpose. The second purpose of the oil is to conduct heat away from the cutting edge. Not only does this preserve the cutting edge by reducing erosion, it also prevents the steel of the barrel blank from expanding. This would cause the cutting tools to bind and it would also cause the finished bore to be very slightly oversized when the steel cools and contracts. But the most important role of the cutting oil is to flush the chips out of the hole and away from the cutting edges. In the case of the reamer, keeping the cutting edges clean and free of chips ensures that the cut will be as smooth as it can possibly be. As for the deep-hole drill, it is absolutely imperative that the high volume of chips produced be flushed out continuously to avoid compaction of the chips in the V-groove of the drill and shank. If the chips are not flushed away with sufficient urgency during the drilling operation, the V-groove will very quickly become packed with chips and this will actually push the drill off-center. Since the objective is to drill the straightest hole possible, this sort of thing can't be tolerated.

Since the volume of chips produced during drilling so vastly exceeds the quantity produced during reaming, it is the drilling operation that sets the requirements of the high-pressure oil system for the machine. Deep-hole drill manufacturers provide charts to determine the amount of flow and pressure required for their drills based on the diameter of the drill and the speed and rate of feed used to accomplish the cut. There are also figures that can be used to determine a maximum speed for drilling when the oil flow and pressure can't be brought up to the recommended levels. It is strongly recommended that you use the charts provided by the manufacturer of your particular drill(s). The geometry of various brands of deep-hole drills is very similar, but there can be minor differences between them.

Unlike the motors used for the spindle and leadscrew, which don't require a lot of power because the load is relatively light, the motor used to drive the hydraulic pump has to work very hard to produce the kind of flow and pressure that this type of machining demands. Likewise, the pump should be sufficiently large that it doesn't have to be spun at breakneck speed to produce the output required. When building a machine like this, it seems that the most difficult challenge will be to fabricate and align all of the components that actually do all of the high-profile work. The high-pressure oil system almost seems like an incidental afterthought. But brother, in this case, appearances are definitely deceiving. While building the machine per se is in fact the most rewarding part of the project, getting the speed of the drill-cut properly balanced with the maximum output of the high-pressure oil system is, by far, the most frustrating quandary you are likely to face as a barrel maker. Actually, if you make only small-bore barrels, the high-pressure oil system may not impose any undue or unforeseen complications in your barrel making future. But once the bore size increases above 30 caliber, things can get interesting in a hurry. Even when using my smallest drill diameter of .5700", the sheer volume of chips produced taxes my oil system to its limits. However, there is a simple

solution that allows me to drill holes far larger than this. I just have to reduce the speed of the cut so that the rate of chip production remains within the chip removal capabilities of my high-pressure oil system.

Because of the surprising importance of the high-pressure oil system to the overall performance of the machine, we will first look at the flow and pressure requirements to run various sizes of deep-hole drills at maximum cutting speed. Then we will look at the maximum practical flow and pressure that can be achieved in a small shop with limited resources and how to adjust the cut itself to compensate for any deficiencies in the available equipment. We will wrap up the chapter by looking at the plumbing required to get the oil to the cutting edge and then safely back into the reservoir to be recirculated.

Drill Speeds, Feeds and Oil Requirements

I obtain my deep-hole drills from Sterling Gun Drills, so I will be presenting the information that they provide for their drills. As mentioned earlier, if you buy drills from another manufacturer, you should use the information that they provide because the geometry and materials that they incorporate into their drills may differ significantly. It is important to remember that the values given in the charts are *maximum* values for the various parameters. All but one of the parameters can be reduced to balance with one or more other parameters that are not operating at maximum. The one exception to this rule of thumb is feed rate. *Do not* deviate significantly from the recommended feed. If the feed rate is increased, the load on the drill will be too high causing chatter and possibly pushing the drill off-center. If the feed rate is decreased, the drill will have a harder time getting a bite in the steel, especially if the drill is almost dull enough to require sharpening, and this can cause it to rub against the head of the hole instead of cutting. Rubbing will significantly increase the rate of heat production and cutting edge erosion.

Recommended cutting speeds are based on the hardness and chemical composition of the material being drilled. Together, these physical characteristics determine how difficult it will be for the drill to cut and displace material from the workpiece. The harder it is for the drill to accomplish its job, the slower the cut has to be made in order to obtain good tool life. The following chart provides recommended cutting speeds for some common barrel steels. There are two different speeds provided, one for the high-pressure oil systems of commercial gun drilling machines and a slower speed for a Spraymist system. The Spraymist figure can be used for machines with coolant pressures that are at least ⅓ gun drilling machine pressure. The original information from the manufacturer comes with this statement: "The information below is a starting reference only!" This means that the figures presented here can and should be used for *planning* a drilling operation. However, good observation and common sense can and should be used for *adjusting* a drilling operation to suit a particular drilling machine's capabilities.

Grade of Barrel Steel	*High-Pressure (sfm)*	*Spraymist (sfm)*
12L14	330	220
1137 & 1144	280	190
4140	180	130
416R	210	140
410	160	110

These cutting speeds are based on the assumption that both the deep-hole drill and the drilling machine are in good condition. The speeds are also based on the assumption that the feed rate used will be appropriate for the drill diameter and material being cut. As with cutting speed, the proper feed rate is somewhat dependent on the hardness and chemical composition of the workpiece. However, the most important factor in determining feed rate is the diameter of the deep-hole drill itself. As the diameter and stiffness of the drill increases, so does the amount of applied force it can stand up to. This allows a faster rate of feed to be used so that tool life is maximized. Again, of all the parameters involved in the deep-hole drilling operation, feed rate is the parameter that offers the least flexibility to make allowances for the individual quirks of a given machine. The recommended feed rate must be very closely followed. The following chart lists the feed rates for different sizes of drill in different types of material. These figures are actually 20% lower than those you will find in a standard feed rate table. The reduction in feed rate is based on the manufacturer's recommendation that feed rate be reduced by 20% for drills with a length to diameter ratio over 30:1. All deep-hole drills long enough to drill rifle barrels fall into this category, so for our purposes, the reduced feed rate is the only figure that applies to our particular application.

Diameter (inch)	*Medium Carbon Steel (inch/rev)*	*Stainless Steel (inch/rev)*
.125″	.00012	.00012
.187″	.00024	.00024
.250″	.00036	.00036
.375″	.00056	.00048
.500″	.00064	.00056
.625″	.00080	.00072
.750″	.00104	.00088
1.000″	.00144	.00120

Obviously, you will not be able to adjust the feed rate to a level of accuracy measured in hundred-thousandths of an inch per revolution. But carrying the figure out to five decimal places ensures that you will get a very accurate calculation of how far the drill needs to be fed *per minute*. And getting this figure as accurate as possible is what you want because it is this feed rate per minute that will actually be set on the DC speed control of the leadscrew motor.

The maximum values of drill speed are to be used only when the cutting oil flow and pressure are also going to be at maximum value for the entirety of the drilling operation. Generally speaking, small drills require very little oil flow at very high pressure. Conversely, large drills require copious flow of oil but at much reduced pressure. The oil has to flow out of the small hole at the tip of the drill and this hole naturally has to be far smaller than drill diameter. The exact diameter of this hole determines the pressure required to obtain a given rate of oil flow. So the optimum oil pressure is almost entirely dependent on the cross-sectional area of the hole in the drill tip (the viscosity of the oil also plays a role). Some manufacturers of deep-hole drills use a plain round hole while others use a kidney bean-shaped hole to increase the cross-sectional area while still allowing the hole to fit well within the periphery of the drill without sacrificing the strength of the tool. So again, the deep-hole drill manufacturer

should be consulted to determine pressure and flow requirements for their drills. The following chart lists the pressure and flow required to drill at maximum rates of speed with drills that have single cutting flutes and round oil holes.

Diameter (inch)	*Oil Pressure (psi)*	*Oil Flow (gpm)*
.125″	1500	1.0
.187″	1150	1.8
.250″	925	2.3
.375″	675	4.5
.500″	525	7.0
.625″	450	9.0
.750″	400	11.5
1.000″	250	17.0

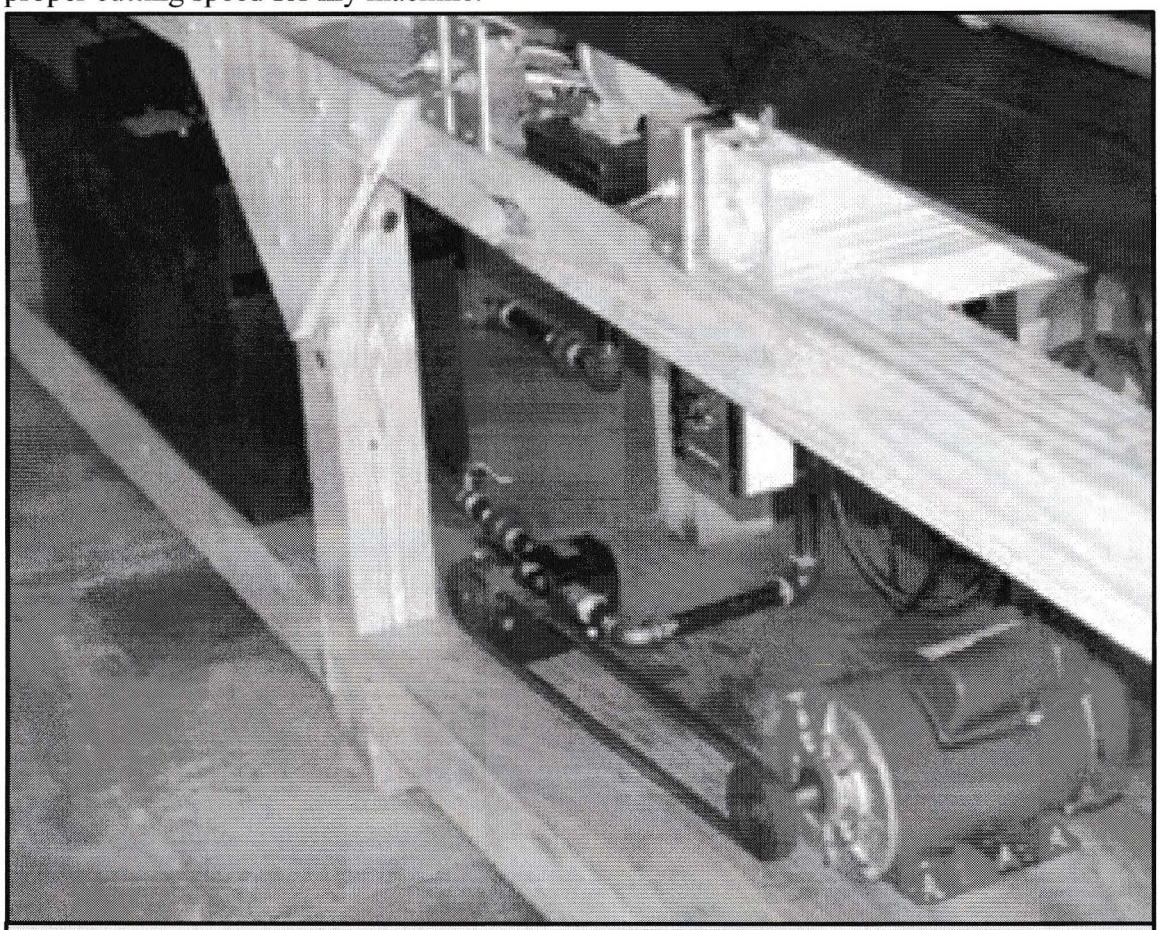
As you can see, it is going to be harder to meet the requirements for maximum drilling speed with a large drill than it will be to do the same when using a small drill. To drill very large diameter holes at high speed requires a large hydraulic pump and a very powerful motor to drive it. We will look at exactly how much power we're talking about in the next section. But before we move on, there is one more parameter to discuss as it relates to pressure and flow and that is the viscosity of the oil. Good cutting oil has both high lubricity and low viscosity. The oil's lubricity allows it to do its job well while its viscosity allows it to be pumped relatively easily. But it is important to realize that, as the oil heats up from the continuous friction of the cut, its lubricating properties and its viscosity will both decline. This makes it an absolute necessity to keep an eye on the machine while drilling. The pressure will drop a bit as the oil becomes warmer because it flows more easily. But since it is also declining in slipperiness, the pressure has to be brought back up by adjusting the flow or the drill will begin to bind. Drill binding will cause the hole to run off-center. Trust me, I've seen it happen with my very own eyeballs. We will discuss this more thoroughly when we get to the chapter concerning the actual machining of a rifle barrel.

Adjusting the Parameters

It would be very nice to be able to afford a large, robust deep-hole drilling machine that is fully capable of drilling any size hole with maximum haste. But unfortunately, most of us don't have enough cash lying about the place to dash out the door and buy the latest and the greatest. Luckily, we don't need to be able to afford such extravagant behavior to get the job done. With a bit of ingenuity and perseverance, we can build a machine that is as fully capable as the store-bought variety with but one caveat– we'll have to ease our foot off the accelerator just a bit to give our machine the time it needs to do what has to be done.

Up to this point, we have given up nothing to the commercial machines in terms of absolute capability. The spindle and leadscrew of the small-shop barrel machine can easily be bestowed with enough power to produce chips faster than a politician can produce inane flapdoodle (and that's pretty fast). But we run up against the wall when we're faced with the high-pressure oil system. If you have the option of installing a 220V, 3-phase circuit in your shop, you should be able to build a stout enough oil system to run with the big dogs. If, however, this is not an option, then you're stuck with a 110V,

single phase circuit and that means that you're also stuck with a 1½hp motor. Installing a 220V circuit in my shop was not an option, so I had to learn how to make peace with a high-pressure oil system that only has one and a half horses in the stable (I know, what's half a horse? I dunno, a centaur?). Fortunately, I've found that this sort of minor handicap is pretty far removed from the proverbial end-of-the-world. All I had to do was determine exactly how much pressure and flow I could get and then experiment a little to find the proper cutting speed for my machine.



The oil reservoir, hydraulic pump and motor sit on the lower shelf of the machine bench.

In order to determine just how much pressure and flow I could get from my high-pressure oil system, I had to first determine how fast I could run my hydraulic pump with a 1½hp motor. The hydraulic pump I installed on my machine was the largest pump that I could get my hands on. It is a Haldex Barnes hydraulic gear pump rated for a maximum pressure of 1,800 psi and a maximum speed of 5,000rpm. This pump displaces .711 cubic inches of fluid per revolution and has a 3" pulley mounted on its shaft. There are about 231 cubic inches in a gallon of fluid. This means that my pump will displace 3.078 gallons per 1,000 revolutions. My 1½hp pump motor runs at 1,725rpm. I did some calculations and determined the flow rates that my pump could produce by varying the size of pulley mounted on the motor shaft. I then did some more calculations to determine how much pressure could be generated at these rates of flow with a 1½hp motor. Keep in mind that, with a pulley of a given diameter, *the flow rate is fixed.* The pump *must* displace a certain quantity of oil when spun at a given rate. It can't be any other way. The

only parameter that I can adjust is the pressure (more on that later). The following chart lists the maximum pressure that my motor can handle at the available discreet increments of flow rate with different sizes of pulleys on the motor shaft.

Pulley Diameter (inch)	*Pump Speed (rpm)*	*Oil Flow (gpm)*	*Maximum Pressure*	*HP Required*
3″	1725	5.3	400	1.492
4″	2300	7.1	300	1.491
5″	2875	8.9	240	1.496
6″	3450	10.6	200	1.492

HP Required = GPM × PSI × 0.0007

With the drill sizes that I use, I would like to be able to generate, for example, 525psi at a flow rate of 7gpm. But, as you can see from the chart, I am only able to generate 300psi at this rate with my motor. The actual pressure on the delivery line is controlled by use of a flow control valve on a by-pass line that returns oil directly to the reservoir without traveling through the deep-hole drill. Since the total oil flow is determined by motor speed, the only way to adjust pressure is by adjusting the amount of oil that has to squeeze through the tiny hole at the end of the drill. Less flow through this aperture (and more flow through the by-pass) means less pressure in the delivery line. As an informal check of the accuracy of my calculations for maximum pressure with my motor, I have tried increasing the pressures above the values listed in the chart by closing off the flow control valve completely to see what would happen. What happens is that, although the motor will indeed crank the pump at higher pressure, it moans, groans and quickly gets hot enough to trip the breaker on the motor. Doing this as a standard practice would inevitably lead to burnt windings and brushes in the motor. This practice also provides a *very* exciting few seconds of abject terror when the pump shuts off without warning and I go scrambling like a lunatic for the machine's switches. Remember, the spindle and leadscrew have their own motors which will blissfully continue spinning in complete ignorance of the fact that the lifeblood of the machine has stopped pumping. And that is a very bad thing. It is much better practice to ensure that the pump motor is operating within its capabilities. In other words, overworking the pump motor will do more to raise your blood pressure than it will to raise the oil pressure, so don't do it.

The knowledge required to determine just exactly how fast to cut with reduced oil pressure can't be gleaned from a chart. You have to listen to what the drill is telling you. When the drill begins to squall (just a quick little chirp every once in a while), that is a sign that you have reached maximum speed. The quality of your finished holes at this point will vary somewhat from one barrel to another. If the speed is increased further, those little chirps will become longer in duration and more frequent until they blend together into an appalling cacophony. This is a sign that the cutting speed has definitely exceeded the oil system's capacity for lubricating the cut and removing the waste. At this point, your barrel blank will be little more than scrap metal with a rough, crooked hole drilled through it. Decreasing the speed of the cut is compulsory when this occurs.

If you simply must drill at maximum speed, you will be able to keep the oil flow and pressure high enough to do so with a 1½hp motor for drills up to ¼" in diameter. A 2hp motor is required for larger drills up to ⅜" in diameter. If your heart yearns for a rifle chambered to fire a brute of a cartridge like the .577 Tyrannosaur, you will need a pump

motor with a rating of 3hp to get that particular job done with all possible haste. Now there is certainly nothing wrong with running deep-hole drills at maximum cutting speed if you choose to do so. In fact, the manufacturers make the things capable of drilling at high-speed specifically so you can get the hole drilled quickly and then move on to other pursuits. But nothing in life is free and putting together a high-pressure oil system capable of decreasing the amount of time spent drilling will set you back quite a few more dollars than a less vigorous system that demands a little more patience. There is another potential cost associated with the higher cutting speeds and that is the quality of the finished hole. The holes I drill with my machine at slow cutting speeds take more time to complete, but there is very little run-out at the head of the hole when the drilling operation is complete. The straightness of the holes that my machine can produce is pretty impressive, especially when the size of my drills is taken into account. I've gotten as little as .002" of run-out over the length of a 32" hole, and that is far straighter than the typical tolerances allowed on the mass-production machinery of the major firearms manufacturers. Of course, the majority of major manufacturers hammer-forge their barrels after drilling, and that process doesn't necessarily require the straightest possible hole. I've never tried drilling a large diameter hole at high cutting speeds, but I would be willing to bet that the finished hole would have considerably more run-out if I did. But if you'd like to at least have the option of drilling at high cutting speeds, the chart below will give you an idea of how much power will be required at the hydraulic pump to keep the oil flowing with sufficient force to make it happen.

Diameter (inch)	*Oil Flow (gpm)*	*Maximum Pressure*	*HP Required*
.125″	1.0	1500	1.05
.187″	1.8	1150	1.45
.250″	2.3	925	1.49
.375″	4.5	675	2.13
.500″	7.0	525	2.57
.625″	9.0	450	2.84
.750″	11.5	400	3.22
1.000″	17.0	250	2.98

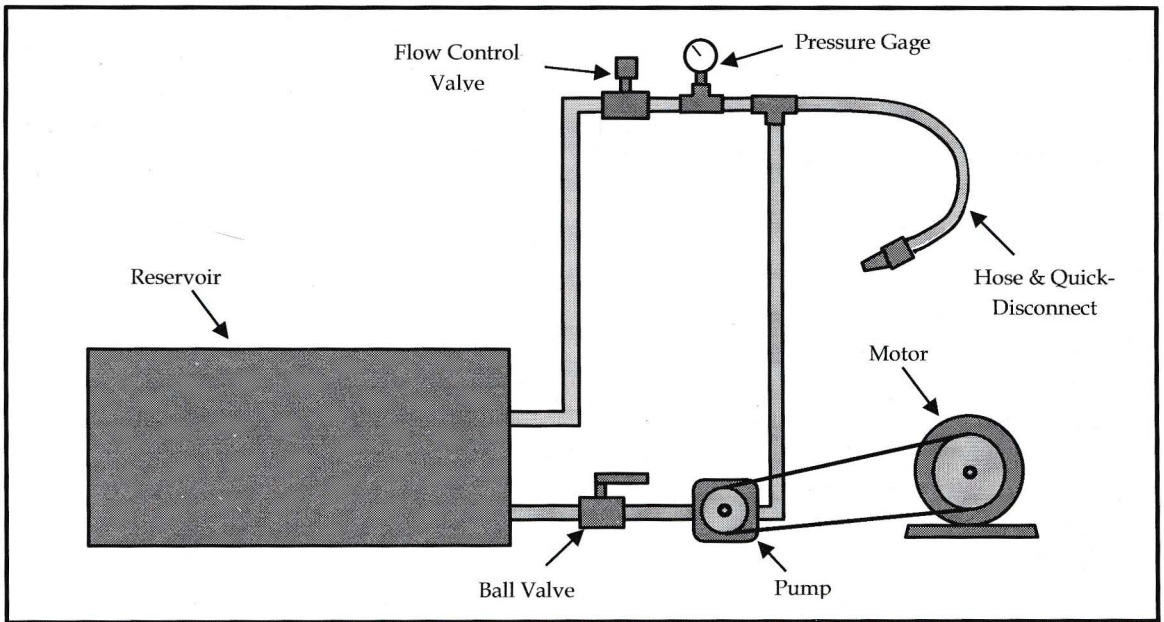
HP Required = GPM × PSI × 0.0007

As you can see from this chart, I could make good use of a 3hp motor on my hydraulic pump. Actually, with this much power at hand, it would be a very good idea to scale up my pump as well. But as I mentioned earlier, installing the electrical circuit required to run a 3hp motor wasn't an option in my shop and the cost involved in the upgrade is simply too high for what I would get in return. With the oil flow and pressure that can be achieved with my 1½hp motor, I have found that a cutting speed of about 60fpm works best. The rate of chip production is low enough for my less-than-absolute-maximum high-pressure oil system to keep up without causing the drill to bind or wander. This cutting speed is about half the recommended maximum speed for a machine that can produce at least ⅓ of the pressure of a commercial deep-hole drilling machine. Knowing how deep-hole drills behave at the speed, flow and pressure that I employ for drilling, I can't help but wonder about the quality of the holes produced at maximum speed. They may not be worth drilling, at least not when a cut-rifled barrel is the desired final result. In terms of time added to the drilling operation, when I'm making an 8-bore

barrel (.8100" drill diameter), it takes me 3 hours to drill the hole whereas it would only take 1½ hours if I could get the oil flow and pressure up to maximum. On the surface, this seems like quite a lot more time, and if drilling was the only operation required in making a rifle barrel it certainly would be. However, the most time consuming task when making a cut-rifled barrel is the cutting of the rifling, not the initial creation of the hole by drilling. To cut ten grooves into that same 8-bore barrel to a depth of .008" requires *two full days* of very meticulous labor. When viewed in that light, what does an extra hour and a half of very low-intensity labor matter? When you throw in the fact that the bore of the barrel will very likely turn out straighter with a lower cutting speed (and I'm not the only one who believes this to be true), the extra monetary investment required for a more robust oil system just doesn't really seem worth it to me. But, of course, this is a judgment call that you will have to make for yourself.

Oil Reservoir, Plumbing and Filtering Components

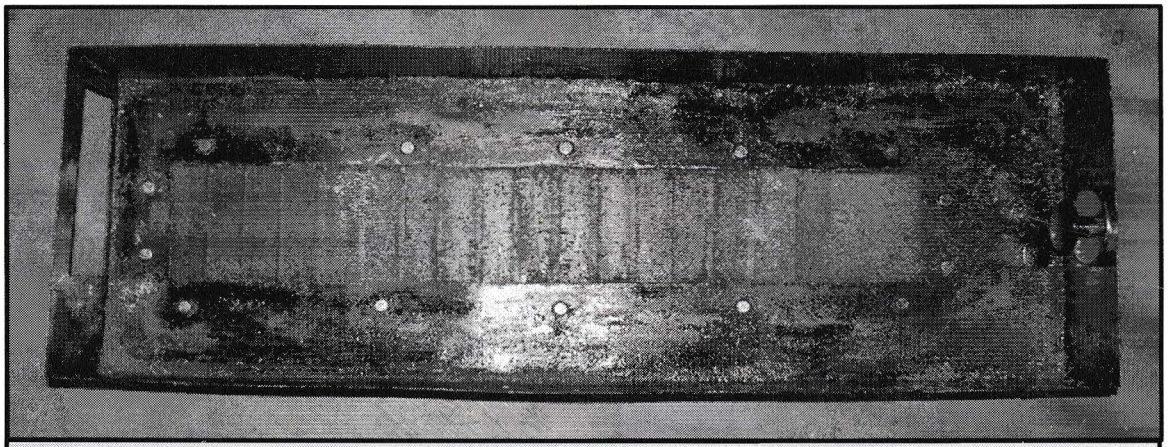
The remaining components of the high-pressure oil system are used to route the oil to the cutting edge, remove the steel chips from the oil and recover the oil to be recirculated through the system. These are the major tasks. But the plumbing components of the high-pressure oil system also have a couple of secondary functions. The oil reservoir plays a key role in keeping the temperature of the cutting oil low enough to retain sufficient lubricity and viscosity simply by having a fairly large storage capacity. And, as mentioned above, the flow control valve and pressure gage work in concert to allow the oil flow to be adjusted as needed to maintain enough flow and pressure to make the cut without overworking the pump motor.



This is the basic layout of the components of the High-Pressure Oil System.

The oil reservoir is nothing more than a simple metal tank used to contain the supply of cutting oil. If you make your own tank, you can adjust the dimensions to fit nicely under your machine bench with enough room to spare that you can remove the collected chips from the chip collection basin (or whatever filtering arrangement you install on your machine). The capacity of the reservoir should be at least 10 gallons. It

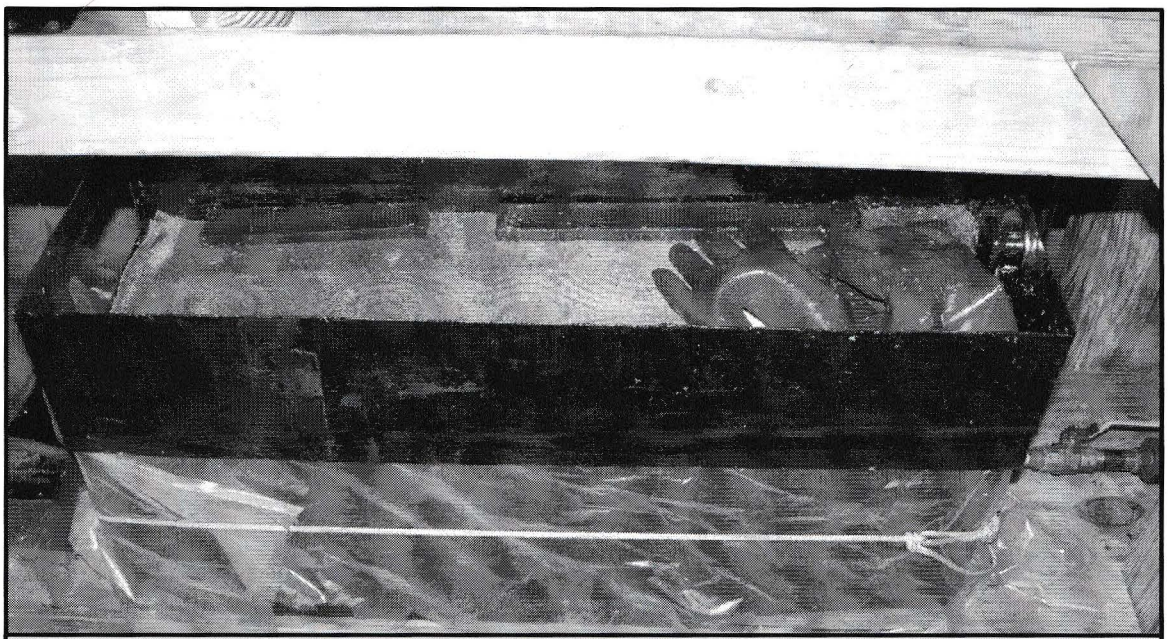
takes this much oil to absorb the heat produced during the drilling operation without allowing the oil to get so hot that its lubricity and viscosity drop below useful values. The reservoir needs to have a supply line leading to the hydraulic pump. This line has a ball valve and a union. If something goes wrong with the pump, the valve can be closed and the union uncoupled to allow removal of the pump without draining the reservoir. The reservoir does not require a return line per se because the oil will return by gravitational feed from above after exiting the chip box. However, there does need to be a by-pass line that returns directly to the reservoir for the purposes of flow/pressure control of the oil being delivered to the drill tip. I also put a union in this line close to the reservoir. This union allows me to empty the reservoir and remove it from the system for repair in the event that it springs a leak due to corrosion or mishap.



The chip collection basin has one layer of permanently mounted screen with magnets beneath. A layer of HVAC filter and another layer of screen are placed on top before drilling.

The lid of the reservoir on my machine also doubles as a chip collection basin. There is a long slot cut in the basin at 3" width. On the underside of the basin, I attached small sections of angle iron around the perimeter of the opening. All seams under the angle iron and at the joints between sections are sealed with Permatex. This apparatus serves two functions. First, it anchors and supports a mesh screen across the opening to catch the chips produced during the drilling operation. Second, the angle iron effectively forces the oil to drop below the level of the basin bottom. This ensures that the oil *must* drop back into the reservoir instead of clinging to the underside of the basin and running out the sides to make a mess on the floor. Now, it turns out that one layer of screen is not sufficient to catch all of the chips produced by the drill. The reason for this is that the chips coming off of the cutting edge are very thin. These thin chips tend to fracture off as a new chip pushes up from the cutting edge. Often, the chips fracture so frequently that they are basically very tiny needles when they come out of the chip box. The screen will catch them just fine if they land on it sideways. However, if they land point down, they are so thin that they simply slip right through the screen. To help prevent this, I added a second layer of screen on top of the first. I also added a section cut from a fiberglass HVAC air filter between the two layers of screen to make it even more unlikely that the chips can sneak through. But the needle-sharp chips are like miniature Houdinis and some of the little escape artists still made it through. As a final line of defense, I installed bar magnets under the basin that rest on the angle iron around the opening's perimeter. The height of the angle iron keeps the magnets far enough away from the screen that

chips can be periodically removed from under the chip box during the drilling operation without magnetically resisting removal. This filtering system leaves a lot of room for improvement in terms of absolute effectiveness. But despite its faults, this system does allow the chips to be filtered out under the influence of gravity alone. More complicated and efficient filtering systems require a pump to get the oil through them fast enough to avoid backing things up and running the system dry. And my pump motor is already taxed to the limit.



This is the clearest photo I have of the chip collection basin sitting on the reservoir. The reservoir is draped with plastic for storage to prevent evaporation of the volatile ingredients in the cutting oil; the plastic provides enough visual contrast to allow the basin to be seen in a black and white photo.

Initially, I installed a micro-screen strainer inside the reservoir at the outlet. The strainer was very good at removing the last few pesky chips from the oil, but I found that it placed too much of a demand on the pump motor. Instead of only working to pump oil *to* the drill, the pump also had to work to suck oil *from* the reservoir through the strainer. This additional demand on the pump caused me many hours of frustration and fruitless fiddling with the flow control valve to try to get the system to work as it should. After adding the additional mechanical and magnetic filtering components described above, I removed the strainer altogether and my pump can now operate at its full potential with the available power source. The occasional errant chip does find its way into the pump and the pump will eventually show signs of wear as a result. But the improvement in pump efficiency is great enough that I am willing to accept the fact that the pump will undoubtedly have a shorter lifespan. Actually, the chips are so tiny and soft (relative to the hardness of the pump gears) that I'm betting that my barrel making days will be over long before the pump eats enough stray chips to be adversely affected, but only time will tell. If you want to install a more positive filtering system on your machine to protect your pump, just be aware that the horsepower demand at the pump will go up quite a bit with the installation of a filtering system capable of capturing every single chip. Judging by the frequency with which I hear my pump chewing on chips (probably about one chip

every five minutes) compared to the total volume of chips produced, I'd estimate that the make-shift filtering system on my machine captures at least 99.9% of the chips produced. I feel that this will keep my pump running for a long time to come and certainly doesn't warrant the costly upgrade in equipment that a more efficient filtering system would require. Installing a new pump about once every decade or so will cost far less in the long run.

The outlet from the hydraulic pump is a black iron pipe that goes up to a T-fitting at machine level. One side of the T is piped back to the reservoir as a by-pass line. I installed the pressure gage and flow-control valve in this section of the plumbing. Obviously, the pressure gage needs to be mounted on the pressure side of the valve. Note that a flow meter is not required. As mentioned above, the pressure at the maximum flow rate is determined by the size of the hole in the tip of the drill. So if pressure is at maximum, then flow must also be at maximum for a given drill size. The other side of the T is connected to the hydraulic hose that feeds oil to the cutting tool driver adapter and the cutting tools themselves. The hydraulic hose terminates in a male hydraulic quick-disconnect that mates with the female quick disconnect that is affixed to the tooling adapter. It is advantageous to make sure that the T is mounted far enough above the machine bed to allow the hydraulic hose to flex without being pinched off. As the carriage moves, the hydraulic hose has to bend in order to follow.

The oil-return plumbing for returning the oil back to the reservoir during the drilling operation consists of a simple funnel that hangs under the chip box. A separate funnel was used to keep the length of the chip box fairly short. A short chip box is lighter than a long chip box and will, therefore, have less of a tendency to pull the drill guide bushing away from the face of the barrel blank under the influence of the machine's vibration. A short chip box also makes the bushing plate/chip box assembly easier to maneuver and install on the machine.

The oil-return plumbing for getting the oil back home during the reaming operation is a little more involved. After drilling, the hole extends all the way through the barrel blank, so oil runs right out the end of the blank. To catch the oil before it can spray all over the shop, I use a return pipe made of PVC. A muffler clamp is used to mount the pipe to a purpose-built bracket that is attached to the side of the machine bench. The pipe must be of a large enough diameter to allow the barrel blank to fit easily inside it. This ensures that the oil can't drip out of the barrel blank onto the floor. The terminal end of the pipe empties into a trough that extends into the side of the chip collection basin. The trough is lined with magnets of various shapes and sizes arranged in a way that (in theory, at least) will disrupt the flow of oil causing turbulence that will reduce the velocity of the oil and make it easier to remove the chips magnetically. The chips produced during the reaming operation are literally as fine as grinding dust. At this size, screens cannot possibly stop them. Only magnets (or an extremely fine filtering system) have any chance of removing them from the oil.

Last but not least, I suppose it would be a good idea to discuss the cutting oil itself before moving on. The cutting oil should be a very high-quality mineral oil with low viscosity and high lubricity. I strongly recommend that you ask your deep-hole drill manufacturer which cutting oil seems to work best with his tools. For some odd reason that I still don't fully understand, I tried to go it alone to determine the best cutting oil by researching all of the types available and talking to oil manufacturers. I must have spent a

little too much time in the sun earlier that day. In any event, I bought the oil that was recommended by the oil sales guy and it turned out to be worse than worthless for deep-hole drilling. Suffice it to say that I had some pretty serious issues when using that stuff. I finally got my head on straight and called the folks at Sterling and they recommended Swiss Silver-A cutting oil from Genevieve Swiss Industries and I bought ten gallons. The Swiss Silver-A oil is very light, flows very easily (which means it also sheds chips easily) and is *ridiculously* slippery. To top it all off, it costs *half* as much as the worthless stuff I tried before. And, as the story goes, this particular barrel maker has lived happily ever after… I just wish this would have been the first cutting oil I tried for deep-hole drilling operations.

CHAPTER 6: Barrel Tooling

The art of making rifle barrels really isn't about the barrels themselves. It's all about the tools. If the cutting tools are as they should be and they are used as they should be used, the only possible outcome is a well-made, accurate rifle barrel. If, on the other hand, the tools are *not* as they should be, then the only possible outcome is miserable failure. Barrel making, like other types of machining, is a lot like sculpting. The raw steel bar has a rifle barrel trapped inside of it and it is up to the barrel maker to liberate it from its prison by cutting away the bits that confine it. But few machining tasks require the level of precision and care that must go into the creation of a rifle barrel. In order to remove every last trace of steel that isn't part of the rifled bore, but not a molecule more, the cutting tools must be very nearly perfect. Their dimensions cannot be more than a couple *ten-thousandths* of an inch shy of absolute perfection. And in addition to the requirement that the entire tooling assembly be dimensionally beyond reproach, the cutting edges must be maintained in a perpetually razor-sharp condition. There is no such thing as a drill, reamer or rifling cutter box that is "good enough". These precision implements of the machinist's art are either just right, or they are just plain wrong.

Many barrel makers buy all of their tooling from commercial sources. Considering the very high standards that the tools must meet, there is certainly no shame in this approach. But some of us choose to make our own tooling, either out of necessity or a desire to meet the formidable challenge that fabricating our own tooling presents. I bought my deep-hole drills primarily because I don't have the type of equipment that would be suitable for pressing a V-groove into the very long shanks of the drills. I also like the fact that the commercial drills are made of tungsten carbide so that they will last a very long time between sharpenings. I made my rifling cutter boxes myself because I don't have a clue where to buy them ready-made, especially for the caliber of barrels that I make. I also made my own reamers. Now, I'm pretty sure that I could have gotten the reamers from a commercial source. But I'm very sure that the sizes I require would carry a hefty price tag. I also wasn't willing to take the chance that outsourced reamers would be easily adaptable to my machine. By making my own reamer assemblies, I was able to build my machine around the deep-hole drills and then adapt the reamer assemblies to the machine. I also made my own drill guide bushings for the exact same reason– I was able to adapt them to the design of my machine. There is one very important thing to remember before you decide to use my techniques to build your own tools. Because I make only large-bore muzzleloader barrels, my cutting tools are absolutely huge compared to the tooling required to make barrels for the vast majority of centerfire calibers. My *smallest* set of tooling (58 caliber) is large enough to make *ultra*-large-bore, centerfire elephant rifle barrels. Smaller tools will be considerably more challenging to fabricate and far more likely to warp during heat-treatment. And the smaller they are, the higher the degree of difficulty. I've toyed with the idea of making a set of tooling small enough to craft a barrel for the 10 Eichelberger Squirrel wildcat cartridge. Not because I have any particular desire for a rifle so chambered, but because making the tools would be so ridiculously difficult. So far, just thinking about the project gives me a headache of sufficient magnitude that common sense has prevailed. But, regrettably, I *have* done a few really dumb things in my life, so who knows? Maybe someday I will be the proud owner of a rifle perfectly suited for stopping the charge of any enraged bull chipmunks

that might happen to be lurking about the place with malevolent intent... all because I just *had* to ask "I wonder how hard it *would* be to make tools that small?"

Because the cutting tools are of paramount importance, this chapter will deal exclusively with purchasing or fabricating the proper tools for the job. We'll also discuss which grades of tool steel should be used based on the heat-treatment capabilities of the available shop equipment. After that, in the next chapter, we'll start making some chips fly by getting into the actual machining operations involved in turning an unremarkable bar of steel into a testament to the art of rifle barrel making that will outlive the craftsman who created it.

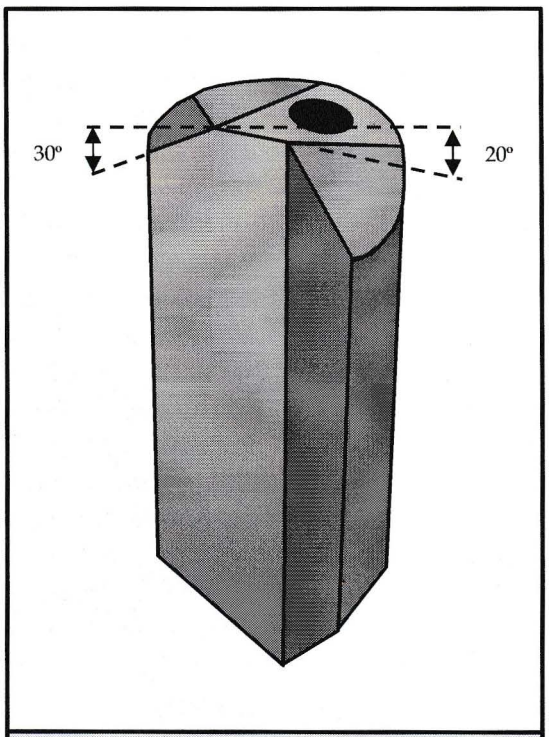
The Deep-Hole Drill

Deep-hole drills themselves would not be excessively difficult to fabricate. It is the shank of the drill that the small-shop barrel maker will have difficulty making. There is nothing especially complicated about the shank. It is just a length of 4130 tubing with a V-groove pressed into it. However, pressing that V-groove into the tube while keeping the tube perfectly straight is no mean feat with the normal compliment of equipment found in a small shop. The best way make the shank would probably be to set up a fixture and roller arrangement on a planer (the kind of planer you cut steel with, not the one you use to thin and smooth wooden planks). Such a setup would provide the necessary workpiece support and smooth, accurate roller travel to ensure a reasonably straight finished product. Lacking a planer, you could also build a small roller machine to accomplish basically the same thing, but the finished shank may not be straight enough for the application. I had initially planned to make my own deep-hole drills, but since I don't have a planer and I had no desire to build a separate machine just to roll V-grooves into the drill shanks, I decided to take the easy way out and buy my drills. Besides, deep-hole drills can be ordered to drill any size hole (specified to the ten-thousandth of an inch) at no additional cost over standard sizes, so the flexibility allowed by the commercial product is nearly unlimited. Even though it is far more practicable for most of us to buy the drills, a brief discussion of deep-hole drill geometry will still be worthwhile just to gain a better understanding of how they function.

The problem with trying to drill a very deep hole with a conventional twist drill is that their geometry places equal and opposite forces on the cutting edges. Because there is no net force, conventional drills can and do flex and wander off-center. This is not a major concern when the depth of the drilled hole is only a couple inches because the drill simply doesn't have enough time to wander very far. However, when drilling holes that are measured in feet, not inches, a conventional twist drill leaves a lot to be desired. To drill really long holes very straight, the workpiece must be spun (instead of the drill) and the drill geometry needs to be specially adapted to the task.

The secret of the deep-hole drill's ability to stay on-center as it cuts lies in the fact that it only cuts on one side. This alone does not entirely eliminate the tendency of the drill to wander because the drill tip still has two cutting edges that are arranged in opposition to each other. However, there is a subtle difference in the geometry of a deep-hole drill's opposed cutting edges as compared to those of a conventional drill. Take a look at the diagram of the cutting edge geometry in the figure. Note that the cutting edge itself is divided into two equal sections at opposing angles. Also note very carefully that the outer portion (at the periphery of the hole) of the cutting edge is ground to a steeper

angle in relation to the face of the drill than the inner portion. Take a moment to recall what you learned about vector forces in high school physics. Because the outer cutting surface is closer to parallel with the drill axis than the inner cutting surface, a net force is produced that tends to force the entire drill away from the workpiece on that side of the cutting edge. This means that a deep-hole drill actually pushes itself *away* from the cut and *towards* the non-cutting half of the drill. This geometry is a stroke of sheer genius. Because the drill can't cut on the side that is being forced hard against the workpiece, it can't possibly wander in that direction. And if, for some reason, it begins to wander in the direction that it *can* cut and the outer edge of the cutting surface drifts farther from the center of rotation, the speed of the cut will increase (cutting speed is a function of cutting radius at a given rate of revolution) causing an ever-increasing net force pushing the drill back the other way. This last bit is the reason that too-high oil pressure or chip packing can cause even a well-designed deep-hole drill to wander. Either of these conditions tends to offset the net force acting in the center-seeking direction. So why not just set the entirety of the cutting edge at an angle that would force it towards the non-cutting side of the drill so that it would be even harder for it to wander off-center? Because that type of geometry would dramatically increase the friction experienced by the wear pad that presses into the barrel blank on the non-cutting side and the drill would soon be cutting undersized holes as a result of excessive wear on that surface. And if you set the entire cutting edge at a single, lesser angle of 5-10°, the net force towards the non-cutting side would be about the same as it is with the two opposing cutting edges, but drill thrust in the opposite direction of drill feed would increase. With conventional deep-hole drill geometry, some of the thrust force is transmitted sideways by both cutting surfaces and cancelled because they are in opposition and this makes things easier on the tool-feeding components of the machine. Getting the drill to cut a straight hole while providing good longevity for both the tool and the machine is a very delicate balancing act.

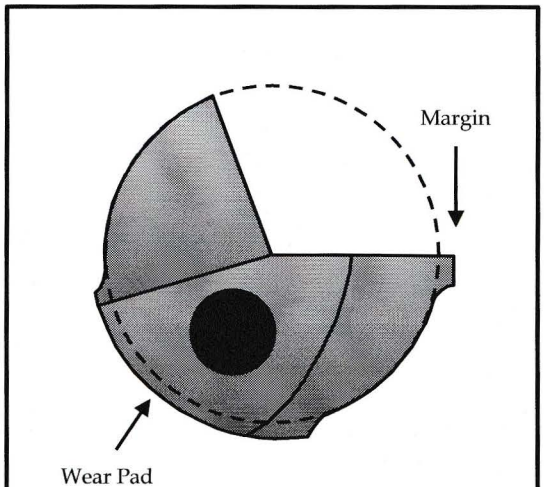


Deep-hole drills have facets on the nose of the drill that are cut at various relief angles. Some manufacturers use radial relief on the nose instead of flat facets.

The relationship between the cutting edge and the centerline of the drill is also critical. The diagram doesn't explicitly show this particular feature of drill geometry. The plane formed by the cutting edge of the drill must be no higher than the centerline of the drill. If the cutting edge were too high, it would leave the core of the workpiece uncut and the drill would then have to force its way past the core by moving it upwards into the V-groove. This is not a good thing for a precision cutting tool to do. Not only would this condition dramatically increase the thrust force on the drill, half-nut and leadscrew, but

that same thrust force would also be transmitted laterally to the drill causing it to wander off-center. The cutting edge of most deep-hole drills is placed precisely on the centerline of the drill and workpiece so that this issue will never arise. However, some drills are ground so that the cutting edge is slightly *below* the centerline. In this configuration, the drill will leave the core uncut, but it will pass smoothly down the V-groove and cause no problems during the cut. When the core is left intact in this fashion, the machining operation is called trepanning instead of drilling. The size of the core that is left untouched by these tools is small, just a slight thread of steel. If you want to make your own drills, it would certainly be advisable to plan the geometry for trepanning instead of drilling. That way, you could rest assured that the cutting edge of the tool is no higher than the centerline so that no problems can possibly arise as a result of trying to push the center of the drill through uncut steel. And as far as I know, trepanning tools cut holes every bit as straight as drilling tools, so there is nothing to lose by playing it safe.

The relief that is ground onto the drill is another important aspect of deep-hole drill geometry. Very little of the actual body of the drill comes into contact with the workpiece. The periphery of the drill is ground down until there are only two lateral points of contact left with the workpiece. One of these points is the margin. The margin lies immediately beside, and forms the outer tip of, the cutting edge. The other point of contact on a standard deep-hole drill is called the wear pad. The wear pad is situated in the quadrant of the drill that lies below the centerline and opposite the cutting edge. This is the surface of the drill that is forced against the side of the hole on the non-cutting side of the drill. This geometry, with only two points of contact, is called the low land configuration and it is used for the vast majority of deep-hole drilling operations. There are, however, other configurations that are sometimes used for specific purposes. These other configurations are called low land and top, high land and high land and top. The alternate configurations are used for drilling specific materials (such as cast iron) or for drilling under specific conditions (cross-holes, angled entry, etc.). If you're not sure whether or not the low land form is right for your application, discuss your specific circumstances with your deep-hole drill manufacturer and follow their recommendations. But for most drilling jobs in most materials, they will likely recommend the low land.



These are the surfaces that bear on the bore. Note that the nose relief on this drill was ground as radial relief rather than facets.

The drill is also ground at an angle in the axial direction to provide complete relief along the rest of its length. As I said before, very little of the drill actually touches the workpiece. Only the cutting edge, margin and wear pad make contact and all of this contact takes place at the very tip of the drill. It is very important that this is the case because the drill must be absolutely free-cutting or it will never be able to stay on course. If any lateral forces (other than those that are planned to act on the cutting edge and wear

pad) are allowed to act upon the drill, the hole that is produced will not be straight enough to be worthy of continuing on to the reaming and rifling operations. The one downside to all of this relief, especially the axial relief along the length of the drill, is that the drill will have to be discarded far sooner than would be necessary with less relief. The reason for this is that as the tip of the drill is ground off and moved back during sharpening, the margin and wear pad disappear rather quickly because they constitute such thin sections of the drill length. Once the margin and wear pad are gone, the drill is no longer capable of cutting full-diameter holes. You can have it reconditioned to cut smaller diameter holes, but then you will also need to size down the couplers on your reamer assemblies to fit the smaller-diameter drilled holes. The take-home message is this: take very good care of your deep-hole drills or there *will* be a price to pay.

The size of the drill driver is determined by the diameter of the drill. Obviously, it takes a large driver to drive a large drill. For most centerfire calibers, the driver will be sized ¾" in diameter. For the really large-bore rifle barrels, centerfire and muzzleloading, the driver size can increase up to 1¼" in diameter. The drill diameter that I use for all calibers is .0100" under the finished bore diameter. The last one hundredth of an inch is removed by the reamer. The following chart lists the standard sizes for deep-hole drill drivers along with their letter designation. Again, this is the nomenclature used by Sterling Gun Drills. Other manufacturers may use different letter or number designations, but the driver size should be the same as this is the industry standard. It wouldn't make much sense for manufacturers to use different sized drivers because then their drills could only be used on machines specifically designed for them, and that would eliminate a lot of potential customers with different machines.

Drill Diameter	*Driver*	*Driver Diameter*	*Driver Length*
.0530-.1249"	A	.500"	1.50"
.1250-.5000"	B	.750"	2.75"
.5001-.7500"	C	1.000"	2.75"
.75001-1.0000"	D	1.250"	2.75"
1.0001-1.375"	E	1.500"	2.75"
1.3751-1.625"	F	2.000"	2.75"

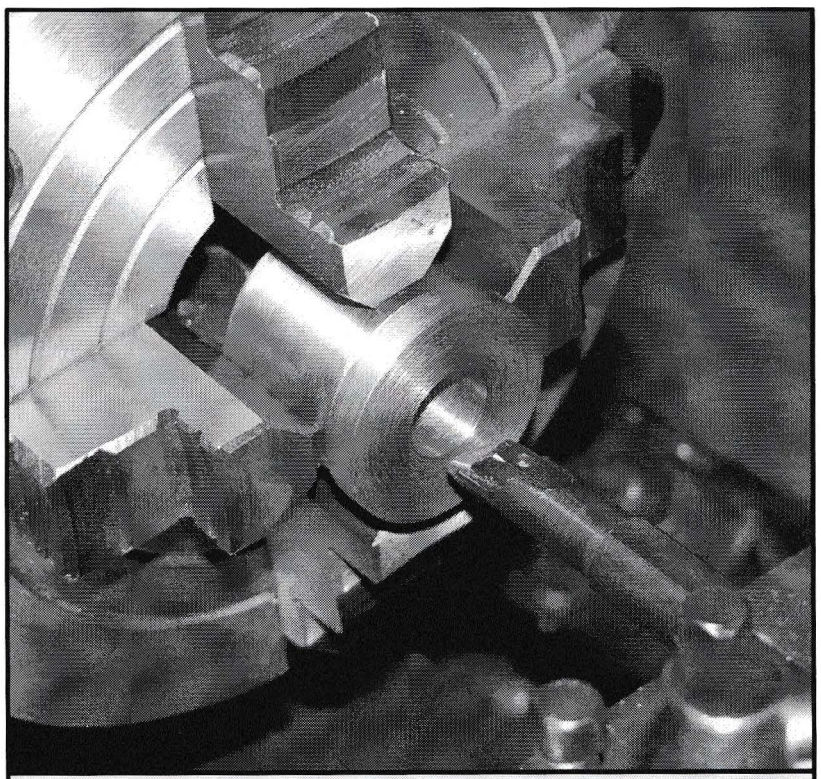
The overall length (OAL) of the drill is measured from the rear of the driver to the very tip of the drill. The OAL must, of course, be at least as long as the hole that you intend to drill. The other factors involved in selecting an OAL depend on the dimensions of some of the components of the drilling machine. In addition to being able to reach the bottom of the intended hole, the drill must also be able to reach through the whip guide (if one is used), chip box, bushing plate and drill guide bushing. And don't forget that the tooling adapter that sits in the universal block will consume a bit of the OAL as well. My drills are sized to an OAL of 44". At this length, I can drill holes up to 32" in length on my machine. So in other words, your drills will need to be about a foot longer than the deepest hole you want to drill. But again, the exact measurement will be based upon the dimensions of your machine. Keep in mind that a drill that is too long for your machine is worse than a drill that is too short. The drill must be fed into the chip box far enough to be able to insert the driver into the tooling adapter with the carriage positioned as far to the rear as it will go. Once it is snugly seated into the adapter, the entire carriage assembly can be moved forward a few inches before the half-nut is locked on the

leadscrew. If the drill is too long to be installed, you won't be drilling anything until you get a shorter drill or reconfigure your machine. If the drill is a bit too short, you'll just have to settle for barrels that are a bit shorter than you originally intended, but at least you'll still be able to make the chips fly.

The Drill Guide Bushing

From this point forward, we are finished discussing commercially available tooling. I made all of the other tooling that I use right here in my shop. Since we just finished reviewing the deep-hole drill itself, it is logical to discuss the drill guide bushing next. The drill guide bushing must be precisely dimensioned both inside and out because there is a critical interface on both the interior and exterior surfaces. The interior must firmly support and guide the drill as it enters the workpiece. Simultaneously, the exterior must mate snugly and securely with the bushing collar if the drill is to be held precisely on the centerline of the spindle.

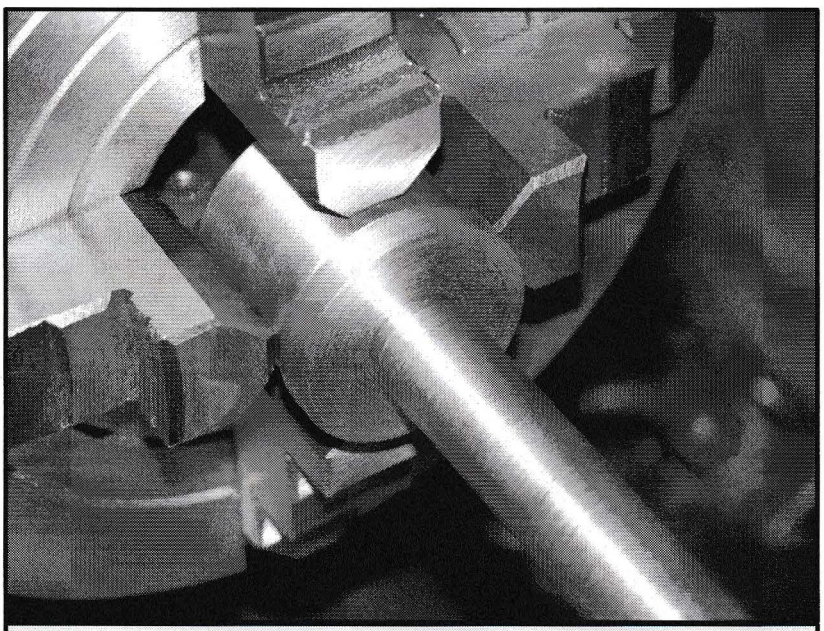
When I'm making a new bushing, I always start the procedure by first fabricating a plug gage to precisely fit the finished dimension of the bored hole. If you happen to have a plug gage that is the correct size (to the nearest ten-thousandth of an inch), then you can skip this step. I make my plug gages out of whatever scraps of round bar that I have near at hand. The plug will not be pressed into service under heavy-duty conditions, so there is no real need to make it out of tool steel or to heat-treat it. When the plug has been reduced in diameter to within a couple thousandths of an inch of final size, I slew the compound rest around to an angle of 5.74° so that each .001" increment of advance on the compound rest hand-wheel will cause the lathe bit to advance .0001" toward the centerline of the machine. When I start getting really close to the final diameter, I stop and measure the plug diameter with a micrometer after each .0001" cut off of the radius. This process continues until the plug measures the same as the diameter of the intended deep-hole drill size within a tolerance of -.0001" to -.0003". At this point, I'm ready to begin the fabrication of the bushing.



The four-jaw chuck is used to bore the hole in the drill guide bushing .

The bushing is machined tail first, meaning that the surface of the workpiece that faces the tailstock will become the rear surface of the bushing. This is done so that the exterior surface of the bushing can be machined concentric first. Since the exterior surface interfaces directly with the bushing collar to keep everything in line with the centerline of the machine, all other surfaces will need to be machined absolutely true with this surface. The rear of the bushing is machined towards the tailstock initially so that when the bushing is turned around to machine the opposite face after cutting it from the raw workpiece, the stop collar on the forward end of the bushing will not be in the way of the chuck jaws.

After the end of the bushing is faced square and the stop collar is cut to diameter (this diameter is not critical, but it does need to be absolutely concentric with the shank for the second lathe setup), the shank of the bushing is turned to the correct diameter by again measuring after each .0001" cut until it is correctly sized to fit the bushing collar. Since the bushing should be a very light press fit into the bushing collar, I use tolerances appropriate for a very light driving fit– +.0002" to -.0000". The shank can be measured directly to determine size or you can use an appropriately sized gage. I use direct measurements simply because the shank is out in the open where it is easily accessed by a standard micrometer. After the shank and collar are sized, I clean up the shoulder of the collar by undercutting it slightly to ensure that there will be no problems caused by a radiused shoulder when the bushing is fit into the bushing collar.

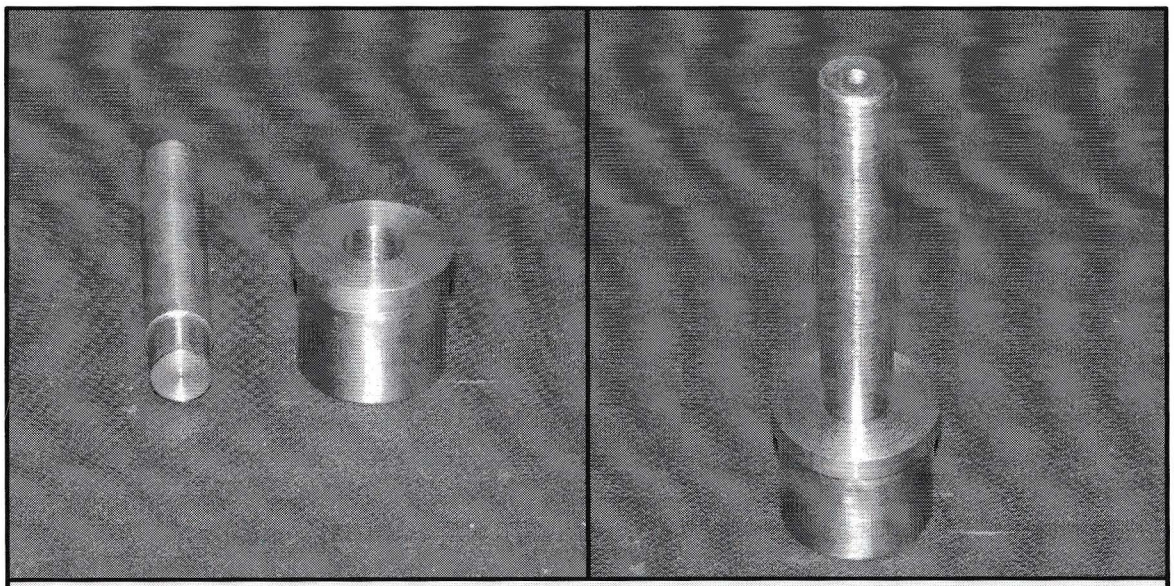


A plug gage is used to check the size of the bored hole.

Once the exterior surface has been turned to size, the bore of the bushing can be roughed out. The bore can be drilled all the way through the bushing to just under the final size. The entire length of the bushing can be bored to the exact size necessary to guide the drill, but this is not necessary. The length of the precisely fitting, drill-supporting section only needs to be ¾" in length to provide the necessary support to the drill. My bushing plate is ¾" thick and the bushing collar is ⅛" thick, so I make the shanks of my bushings a full inch long so that I know they will reach ⅛" into the interior of the chip box. This is done to ensure that all of the oil stays inside the chip box where it belongs. In addition, I also make the stop collars of my bushings ¼" thick just to ensure that there is plenty of space between the barrel blank and the bushing plate. This gives me a total bushing length of 1¼". I drill the rear of the bushing out to a depth of ½" at the next standard drill size larger than the deep-hole drill that the bushing is designed for. By

drilling this section oversize, I reduce the amount of work that needs to be done with the boring bar to bring the interior dimension of the bushing within tolerance. Again, this is not necessary but it does reduce the amount of machine time required to fabricate the bushing. Besides, the taper of the deep-hole drill will prevent the drill body from making contact with the rear section of the bushing anyway, so it does no good to accurately machine the hole longer than it needs to be.

After cutting the bushing off of the longer raw bar, it is placed back into the lathe and very precisely centered in a four-jaw chuck. Do not use a three-jaw chuck for this step unless it is capable of *perfectly* centering the workpiece on the centerline of the machine. One or two thousandths off-center is unacceptable. The face of the bushing is then squared with the body. This cut shouldn't be extremely smooth. You want some tool marks on the face of the bushing. Not only will a slightly rough face reduce the surface area of contact between the bushing and the barrel blank, the tool marks will also provide a space for lubrication to be trapped between the two surfaces so that galling does not occur. Once the face is machined square, the bore of the bushing is machined to final size with an appropriately sized boring bar. The bore is machined away fairly quickly and checked for size with dial calipers until it is within one or two thousandths of the final size. From that point on, the cut is made .0001" at a time and I try to insert the plug gage into the bore after each cut. When the plug gage just barely fits with light hand-pressure, the bushing is finished.



This shows the fit of the plug gage in the drill guide bushing. Note that the friction of the fit is just enough to keep the plug from falling into the bushing to its shoulder.

The working tolerance range for the bore of a deep-hole drill guide bushing is drill diameter +.0004" to -.0002". This is the reason why I like to make my plug gages a bit smaller than they really need to be. Hitting an exact size, measured in ten-thousandths of an inch, is not easy. Let's say that the final cut on the plug gage left it .0003" under drill diameter. I try the gage in the bushing bore and it won't fit, so I cut an additional .0001" off of the *radius* of the bore. Now the plug gage will slide in under slight hand-pressure. Because the *diameter* of the hole has increased by .0002" since I last checked, the best I can say is that the bore of the bushing is no larger than .0001" under drill

diameter and that's only .0005" under maximum diameter. There may be better ways to do this, but by using this technique, all of my bushings have turned out well and I have never had to scrap one because the bore was so large that it wouldn't support the drill well enough to prevent chatter as it entered the barrel blank.

I fabricate my bushings out of 4130 steel. This may seem like a very odd choice of alloy for this application, but there is method to my madness. I do not have the equipment necessary to accurately grind the bores and shanks of the bushings to final size and perfect concentricity with the required precision of a few ten-thousandths of an inch after heat-treatment. Because of this limitation, my best option is to use a steel alloy that will exhibit minimum distortion during the quench. With .30% carbon, 4130 steel has just enough carbon to be hardened by heat-treatment. However, this minimum carbon content also ensures that the dimensions will change very little, if at all, due to warpage when quenched. Other steel alloys would certainly harden better than 4130 and so would be more appropriate for the application. If you have the equipment necessary to grind hardened tool steel to the correct specifications to within a couple ten-thousandths of an inch, then by all means, go ahead and use a more suitable alloy. But the bushing only has to support the drill until the margin enters the workpiece and, since the drill doesn't spin, there is no noticeable wear produced on the bores of my bushings (at least not yet). 4130 has proven entirely satisfactory for this job both in terms of wear resistance and resisting deformation during the quench. I also give the bushing a bit of help in the hardening department with my heat-treatment procedure, which we will discuss next.

The basic heat-treatment procedure that I use for my bushings is the same for the reamers and rifling cutter boxes as well. Because the technique is the same for the other tools, I will only cover the procedure once even though I use O-1 tool steel for the others. So remember this discussion when we talk about the other tools. The main reason that I selected 4130 and O-1 steel to fabricate my tooling is that these alloys don't need to be held at critical temperature for very long before the quench. After pre-heating and then raising the temperature to critical, these alloys only have to be held at critical temperature for 5 minutes *per inch of cross-sectional area.* Since the cross-sectional dimensions of the tools I am heat-treating measure much less than 1", I only need to hold them at critical temperature for a minute or two to heat them all the way through. Since I do not have a furnace and must use an oxyacetylene torch for heat-treatment, this is a very important consideration when choosing tool steel alloys. More exotic tool steels need to be held at critical temperature for 30 minutes or more per inch of cross-sectional area, and that is not a job for an oxyacetylene torch and a stopwatch.

The standard procedure for the 4130 and O-1 alloys is to pre-heat them to 1,200°F (medium cherry-red) until uniformly heated. This will only take a few minutes for the size of tools that we are dealing with here. The pre-heat cycle ensures that the workpiece will be stress-relieved and uniformly warm before heating to critical temperature. The critical temperatures for these alloys are slightly different. 4130 has a critical temperature of 1,575°F while O-1 reaches critical at 1,500°F. But with no furnace, I must use color to gauge temperature and the color at these temperatures is bright-red (about 1,550°F). Salmon color is a bit too hot (about 1,650°F). Using color to judge temperature is not as precise as a temperature-controlled furnace, but you will be surprised by how easy it is to differentiate between the various shades of reddish-orange after you've had a bit of practice. I can tell you for a fact that using color in this way will allow you to

successfully harden your tools, and cutting tools hardened in this fashion will indeed hold an edge very well.

Once the workpiece is brought up to pre-heat temperature, and before raising it to critical temperature, I dunk it into a pan full of case-hardening compound. I then bring it on up to critical temperature and hold it there for a few minutes before quenching in oil. The case-hardening compound is used to prevent scale from forming on the surface of the tool. It will also keep the carbon in the tool from being burned away by exposure to the atmosphere while at critical temperature. In the case of the tools made from O-1 with their .90% carbon content, this is the extent of the usefulness of the case-hardening compound. However, for the just-barely-medium carbon 4130 steel, the compound will put just a bit of extra carbon into the surface of the steel. This gives my bushings a case that is a little harder and more wear resistant while still allowing the bushing to quench without warping. As I said before, I have never had to re-make a bushing because it wasn't hard enough or it was too warped to hold the drill precisely on the centerline of the machine, so this method has certainly worked for me. If you want to use a different alloy or heat-treating technique, I assure you that it won't hurt my feelings and you may even get better results than I do. But for those of you who don't care to reinvent the wheel or invest in lots of costly equipment, this simple small-shop technique *does* work very well.

Tempering should take place immediately after quenching when the tools are still about 150°F to get the maximum benefit and best tool life from the temper. After the quenched tools have cooled enough that I can just barely stand to hold them in my hands, I temper them in my kitchen oven, which has been pre-heated to 350°F. The folks who get paid to know such things say that you cannot over-temper steel; it can only be under-tempered. I follow their recommendations and temper the tools for two full hours. The temper cycle is very important because it allows the atoms in the tools to settle into their new configuration. This relieves stress and adds tremendously to the life expectancy of the tool. When the tempering cycle is complete, I just turn off the oven and allow the tools to return to room temperature slowly and evenly. Once they have reached room temperature, they are ready to go.

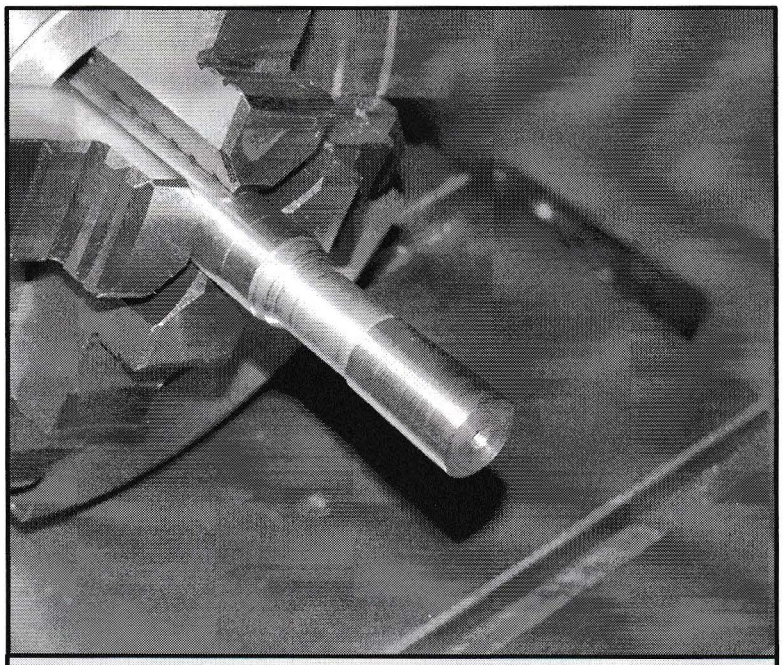
The Reamer

The reamers used to cut rifle bores to the proper size are, in most ways, nothing more than conventional, multi-flute reamers. The primary difference is that rifle bore reamers are designed to be pulled while reamers designed to be used in the tailstock of a lathe or the spindle of a mill are designed to be pushed. Also, like the deep-hole drill, the rifle bore reamer is held in a fixed position while the workpiece is spun. But the basic geometry of the reamers designed for the different types of machine tools is the same. Rifle bore reamer flutes have a lead (taper) section, a parallel section and a chamfer. Only the lead section of a rifle bore reamer actually cuts steel. The parallel section is used only to scrape and burnish the hole while the chamfer does nothing more than ensure that there are no sharp corners to gouge the bore at the last point of contact between reamer and barrel blank.

The length of the cutting flutes on my reamers is 1". This length includes a ¾" tapered cutting section and a ¼" parallel burnishing section. The cutting section is tapered at an angle of 2°. This angle is not written in stone. Reamers can be made with

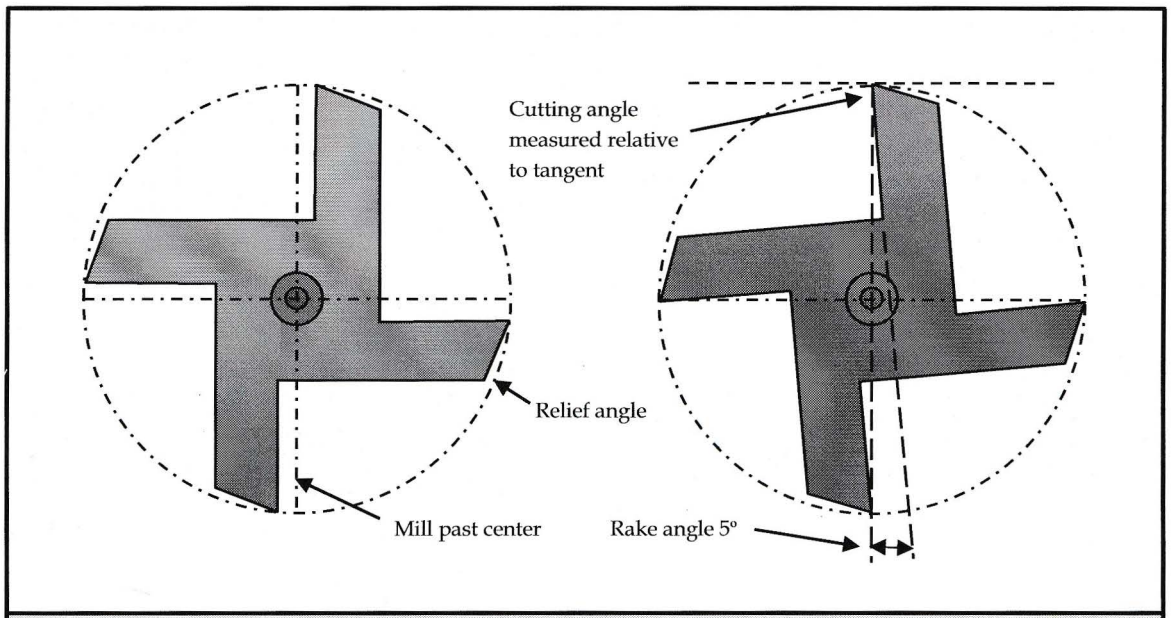
tapers ranging from 1° to 5°. I use the 2° angle simply because this angle works well for a ¾" cutting section that will be used to cut .005" from the radius of the hole. For a given depth of cut, a shallower cutting section angle will need a longer cutting length while a steeper angle will allow a shorter cutting length.

The reamer is turned to shape and size on the lathe. After facing and center-drilling the reamer for the tailstock center, the entire length of the reamer is cut to the size of the parallel section (finished bore diameter) to a tolerance of +.0002" to -.0000". Then a shank is turned onto the back of the reamer. This shank measures ½" long and will be soldered into a coupler later. The shank of the reamer is turned to the inside diameter of the coupler with a tolerance of -.0010" to -.0005". It is very slightly under-sized in this fashion to allow room for the solder to flow. After these parallel sections of the reamer are turned, the tapered cutting section can be cut. The correct taper is cut by using a dial indicator to set the angle of the compound rest to precisely 2°. The hand-wheel of the compound rest is used to feed the cutting tool by hand. The cross-slide is advanced between each cut to increase the depth of the cut. Total in-feed of the cross-slide to produce a ¾" cutting length at 2° is calculated by using the sine of 2°. As an alternative, the remaining length of the parallel section can also be measured. When it is reduced to ¼" in length, the cut is finished. After completing the cut, I polish the surface of the reamer with Scotch-Brite to give it a nice smooth finish. This gives the surface a well-burnished finish without removing a measurable amount of steel from the workpiece. We don't want to polish our brand-new reamer under the proper size.



The fully profiled reamer is ready for milling.

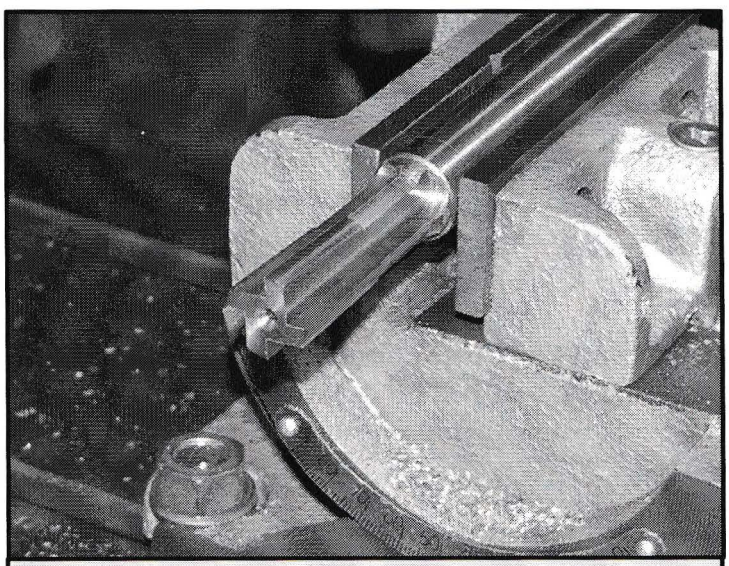
Now that the basic shape of the reamer has been established, the flutes can be milled. All cutting tools designed to remove steel from a workpiece should have a rake angle of 5° to reduce the pressure of the cut. But how do you cut a 5° rake angle with an end-mill that measures 90°? To paraphrase Sherlock Holmes, "it's trigonometry, my dear Watson". After determining the total depth that the mill will have to cut to produce the flutes, use this measurement in conjunction with the sine of 5° to determine the length of the leg opposite the 5° angle. When positioning the reamer under the mill spindle, do not position it so that the edge of the mill will cut to the centerline of the reamer. Instead, go past the centerline by the distance you calculated for the leg opposite the 5° angle. The reamer will cut perpendicular to the radius (not perpendicular to the surface of the cutting edge), so cutting past center by the appropriate amount will produce the required 5°



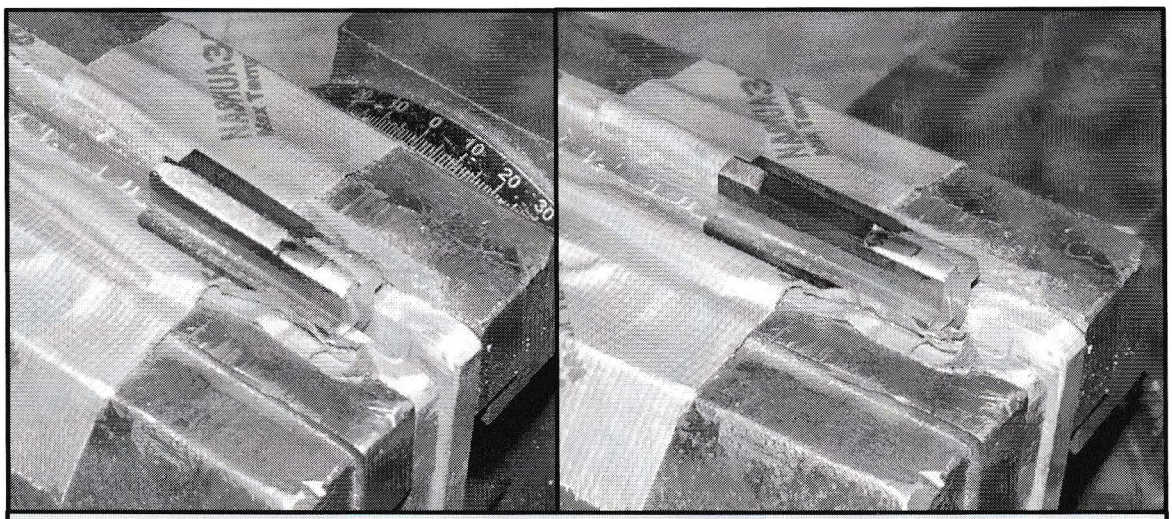
The rake angle of the reamer's cutting flutes is measured relative to the tangent. The angle should be 5° measured from a line drawn perpendicular to the tangent.

cutting angle. The accompanying figure illustrates this principle. There is no need to precisely regulate the length of the cut along the reamer axis. Just make sure that the mill cuts to full width at least as far as the end of the reamer shank. After soldering the reamer assembly together, cutting oil will have to flow through the shank to get to the cutting edges and the flutes need to be cut to full width for the full length of the reamer to make this happen.

Once the first flute is cut, I use a square to rotate and align the reamer for the next cut. The bottom of the flute that was just cut is aligned with the vertical leg of the square to index the next flute. Obviously, this practice will only work for 4-flute reamers. If you want to make a 6-flute reamer, you will have to use another indexing method. This recommendation carries the usual caveat concerning the size of my tools. If you're making a small-bore reamer, the surface that you have available to align with the square will be much smaller (shorter) than mine and the difficulty of using this technique will increase accordingly. The remaining reamer flutes are milled in the same manner as the first. At this point, I cut my reamers off of the raw workpiece material and file the relief on the flutes by hand. If you want to



This reamer is ready to be cut from the raw bar.



The relief angles are filed on both the tapered and parallel sections of the reamer flute's cutting edges prior to heat-treatment. The use of permanent ink or dye is crucial during this process so that the exact location of metal removal can be monitored and controlled.

machine the relief into the tool, you will want to leave the reamer attached to the larger steel bar for a while longer.

I place the reamer in the shop vise to file the relief angle into the flutes. Before filing anything, I color the off-side of the flute black with a permanent marker. I then set my dial calipers to a gap of .010". One jaw of the caliper is set on the top (outside diameter) of the reamer flute and the other jaw is used to lightly scribe the back of the flute. Use only enough pressure to scuff off the marker ink with the tip of the caliper jaw. This scribed line represents the level to which the relief will be filed. When I start getting close to the scribed line, I paint the top (outside diameter) of the flute with the permanent marker so I can see what I'm doing. The idea is to file all the way down to the scribed line on the back side of the flute while leaving a very thin margin adjacent to the cutting edge completely untouched. On the actual tapered cutting portion of the reamer, I reduce the margin to no more than .001" in width. This allows the reamer to cut very freely without producing a lot of friction and chatter. Do not try to remove the margin completely or you will run the risk of under-sizing the cutting edges of the flutes. If the cutting edges are not all *exactly* the same size, the reamer will not work as well as it should. On the parallel section of the flutes, I leave the margin up to .005" wide. This section of the reamer is designed only to scrape and burnish the hole, not cut it. The slightly wider margin increases the burnishing action and also provides a bit more support and stability to the back end of the tool. The final step prior to heat-treating the reamer is to stone the mill marks off of the cutting edge and round off the trailing edge of the flutes to form a chamfer. Trust me, it is much easier to stone these surfaces when the steel is in the annealed condition, so do it now before you heat-treat the part. The chamfer that I use is a simple rounding of the trailing edge of the flutes. The chamfer is not designed to cut at all. Its only purpose is to ensure that the final contact between the reamer and the barrel blank will not be made with a sharp, scratchy corner because such a corner *will* ruin the surface finish of the rifle's bore.

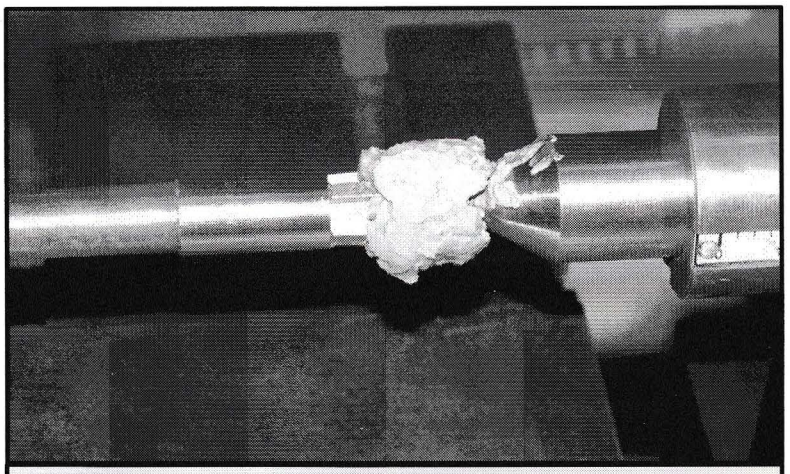
The reamer is now ready to be heat-treated as discussed in the previous section. In actual practice, I complete all of the tooling before heat-treating. This allows me to

heat-treat all of the tools at once and, more importantly, heat the oven for tempering once. You can heat-treat the parts at different times and then just leave them as quenched until they are all ready to temper. However, experts in the field of heat-treatment do not recommend this. For reasons that I do not fully understand, tempering immediately after the quench refines the microscopic structure of the steel's grain better than tempering hours or days after quenching. The more refined the micro-structure of the steel, the longer it will hold an edge. So following the advice of the metallurgists can pay real-world dividends. As I mentioned before, my reamers are made from O-1 tool steel. There are other grades of tool steel that are harder and will hold an edge longer but, unfortunately, they are not as simple to heat-treat as O-1. Unless you have a furnace with accurate temperature control, I recommend that you also use O-1 for your shop-made tools. This grade of tool steel has proven to be up to the task for me even if it does require more frequent sharpening.

Once the reamer is hardened and tempered, it is mounted on a hollow pull-tube so that it can be drawn through the barrel blank while oil is pumped through the tube and over the flutes to flush away the chips. The pull-tube is made from 4130 aircraft tubing. Due to the available sizes of this type of tubing, large-bore barrels offer more options for pull-tube construction than do small-bore barrels. To make large-bore barrels, I use an under-sized pull-tube in conjunction with a short coupler to attach it to the reamer. The coupler is also made of 4130 tubing that has a large enough outside diameter to be turned on the lathe to just under the diameter of the deep-hole drill. The tubing comes in several different wall thicknesses in the larger sizes. It is a fairly simple matter to select a wall thickness for the coupler that brings the tube's inside diameter to just under the outside diameter of the main pull-tube. For small-caliber barrels that require a small diameter pull-tube, this technique won't work very well because there simply aren't as many different diameters and wall thicknesses to choose from. For small-caliber barrels, it is best to use a pull-tube that is just over drill diameter. Turn a short section at the business end of the tube, about an inch in length, to just under drill diameter. Then turn the remaining length of the tube several thousandths of an inch smaller. The larger section will serve to guide and support the reamer (and seal off oil so that it can't flow the wrong way) while the rest of the tube is free to pass through the bore without making contact.

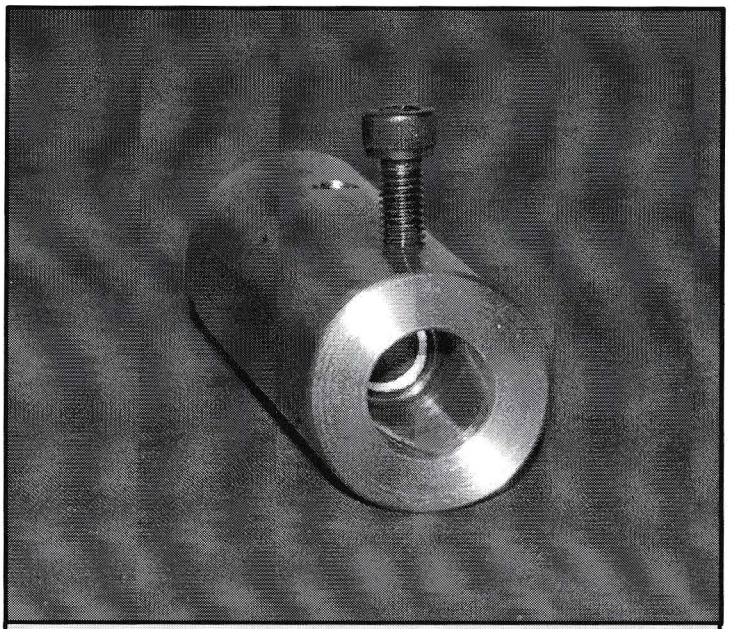
The coupler is sized on the lathe to just a bit under drill diameter with a tolerance of -.0010" to -.0005". This diameter will allow the coupler to slide freely through the drilled bore without binding, yet is still tight enough to support the reamer and block the flow of oil. The inside diameter of the coupler is left untouched. The deep-hole drill guide bushing that was made earlier works as a perfect gage to determine the correct diameter for the coupler. When I start getting close to the final coupler diameter, I advance the compound rest .0005" for each successive cut until the bushing will slip over the coupler's outside diameter. I make my couplers 1" long. This allows me to insert both the reamer shank and the pull-tube into the coupler ½". This has proven to be a satisfactory length for the solder joints. After the coupler is complete, the outside diameter of the pull-tube is turned to the same tolerance under the inside diameter of the coupler for a length of ½". As with the shank of the reamer, the slight under-sizing gives the solder room to flow into the joint between the two pieces. The coupler itself can be used as a go-gage for this cut in the same way that the drill guide bushing was used to gauge the coupler's outside diameter.

With all of the components of the reamer assembly fabricated and ready to go, it is time to solder them together. To ensure good adhesion of the solder joints, all three pieces need to be tinned before assembly to ensure adequate flow of the solder into the joints. I have experimented with several different techniques to tin the pieces. The best method I have come across so far is to use Brownell's High-Force 44 ribbon. A small section of the ribbon is cut and wrapped around the surface to be tinned. Both the piece to be tinned and the solder ribbon are fluxed, and then heat is applied until the solder melts. I keep a few Q-tips handy during this process to wipe off excess solder. You do not want any build-up, just a slight tinning to provide for good solder flow later. When tinning the reamer shank, I smear some Brownell's Heat-Stop Paste on the cutting portion of the flutes to avoid tempering them softer than they should be.



The reamer assembly is soldered on the lathe. Note the Heat-Stop paste on the heat-treated cutting portion of the flutes.

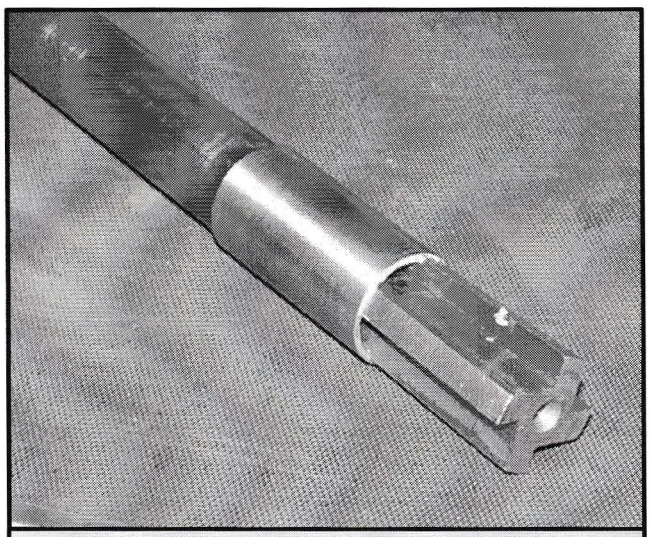
During the assembly of the components, it is very important that the three components be perfectly aligned with each other. So, after the pieces are properly tinned, the lathe is pressed into service as a soldering fixture. The pull-tube is placed in the lathe chuck and centered. Then the coupler and reamer are affixed to the end of it. Finally, the tailstock is brought forward and its center is advanced into the center-drilled hole in the end of the reamer. I like to spin the lathe spindle a few times by hand while indicating the coupler to make sure that everything is as it should be. The reamer flutes are then slathered with a healthy dose of Heat-Stop. Before applying any heat to the assembly, *make absolutely certain* that you have not inadvertently locked the tailstock spindle through simple force of habit. The components of the reamer assembly will expand when they are heated and if the tailstock is locked, the force generated by their expansion will cause the assembly to go crooked. If it's not locked, the tailstock spindle will slide rearward into the tailstock as the components expand and exert force on it, and this allows everything to stay nicely centered. Yes, I learned this lesson the hard way. I once locked the tailstock spindle out of habit and that particular reamer assembly went off-kilter. I had to disassemble the components and start over. When the assembly is brought up to soldering temperature, I use Brownell's Flux-Core High Force 44 solder to join them together. The flux in this solder works very well in conjunction with the pre-tinned surfaces to draw solder into the joint and make a strong bond. This brand of solder is also sufficiently strong to hold the assembly together during barrel reaming operations. If you choose to use commercially available tungsten carbide reamers, you can use silver solder to make an even stronger joint. The carbide won't be tempered by the heat required to melt silver solder. But since my reamers are made of O-1, I choose to stick with a lower-temperature solder so that I won't ruin my reamers in the process of assembling them.



This is a completed reamer driver. Note the snug-fitting O-ring at the bottom of the pull-tube's bore.

The final component that needs to be fabricated is the reamer driver. This piece is made from a short bar of steel that is the same diameter as the deep-hole drill driver and 3" in length. The reamer driver is drilled all the way through at the same diameter as the tooling adapter's through-hole or at least ⅛" under the reamer pull-tube's outside diameter, whichever is smaller. Then, one end is bored out to a snug fit with the outside diameter of the reamer pull-tube to a tolerance of +.0005" to +.0010". The bored portion of the hole should be at least 1" deep to provide good support for the reamer pull-tube. The shoulder produced by the boring bar needs to be smooth and perfectly flat because, in use, a rubber O-ring sits atop this shoulder to form the oil seal between the reamer pull-tube and the reamer driver. A hole is drilled and tapped through the wall of the reamer driver into the bored portion of the driver so that a set-screw can be used to fix the reamer pull-tube into position. Further to the rear, a small flat is spot-milled on the top surface of the reamer driver to accept the set-screw from the tooling adapter. A similar flat is also spot-milled on the reamer pull-tube to accept the set-screw from the reamer driver. Remember to have the O-rings in place in both the tooling adapter and reamer driver when locating these flats or you will mill them too far forward to be used when the O-rings are installed.

One final task remains before you are ready to ream a rifle bore. The reamer flutes must be sharpened to razor keenness. I use a square, fine grit India stone to sharpen my reamers. The stone is held parallel (lengthwise) to the reamer assembly and placed in the milled-out sections of the reamer. Sharpening is accomplished by simply drawing the stone back and forth. Since the corner of the stone forms the same 90° angle as the end-mill that cut the flutes, I don't feel that any sort of a jig is necessary. The only time that I ever touch the margins of the reamer flutes is after the actual sharpening is finished. When a flute has been sufficiently honed, a light burr will form at the very edge of the margin over the full length of the flute. You should be able to feel this burr with your finger. To remove the burr, I push a brass rod across the edge of the flute in the proper cutting direction (towards the flute). As the flute cuts into the brass, the burr will be dragged off with the chip. This will remove the worst of the burr. I then use a small, ultra-fine stone to *very gently* hone the top of the margin, again in the direction of a normal cut. I cannot emphasize enough that this operation must be performed with the utmost delicacy to avoid removing material from the margin itself. I just barely allow the stone to make contact with the margin, almost as if I'm afraid to actually touch it. Come



Reamers must be very sharp. That little white curl on the top flute is a shaving off the back of my fingernail.

to think of it, I *am* afraid to actually touch it. The goal is to remove the burr, the whole burr and nothing but the burr. We're not trying to remove any metal at all from the margin. Once the burr has been cleanly and completely removed, it is time to test the sharpness of the flute. You should be able to draw the back of your fingernail across the flute, using *only the weight of your finger* (not the weight of your whole hand, just the one finger) to hold it in contact with the flute, and shave a small curl off of the fingernail. If the flute is not sharp enough to do this, then it is not sharp enough to ream a rifle barrel and you need to repeat the entire sharpening process again until it is this sharp. "Sharp enough" isn't, so keep after it until the job is done right or the quality of your rifle bore will suffer.

The Rifling Cutter Box

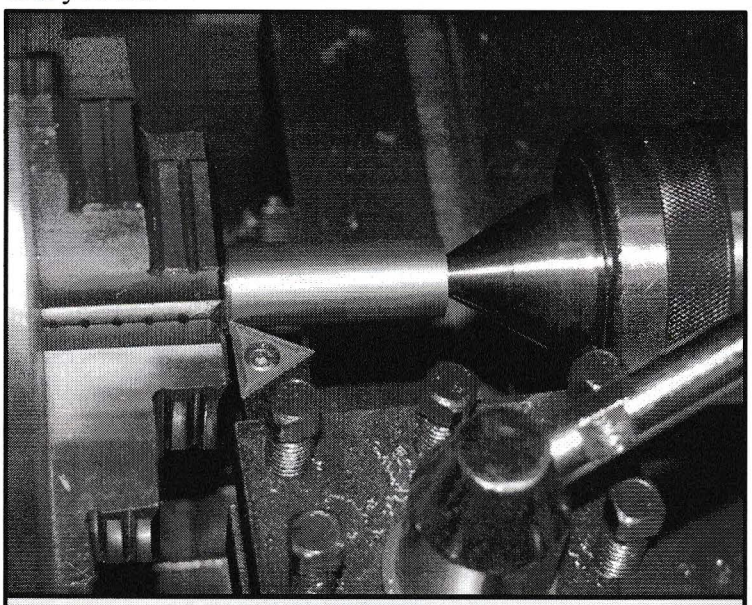
The rifling cutter box is the one piece of barrel tooling that you will likely have no choice but to fabricate yourself. Deep-hole drills and reamers can be bought, if you choose to do so. But I'm not aware of any commercial supplier of rifling cutter boxes. The rifling cutter box is nothing more than a very specialized cutting-tool holder. Its only purpose is to advance the hook cutter in very small increments and hold it against the workpiece during the cut. And, unlike the situation with the reamer, even if you have a heat-treating furnace, there is no good reason to use any tool steel other than O-1 (unless you get a really good deal on a more exotic alloy) because the cutter box itself has no cutting edge. There are two basic types of rifling cutter boxes and both types use a screw to advance the cutter between cuts. The first type of cutter box uses the screw to directly impinge on the forward end of the cutter. The cutter's geometry, coupled with the geometry of the slot in the rifling cutter box that is designed to hold it, causes the cutter to rise up out of the slot as the screw is incrementally retracted from the cutter box. With this type of arrangement, the form of the hook cutter itself and the interior contours of the rifling cutter box are both fairly intricate. The necessary complexity of form makes this type of cutter box very difficult to fabricate in a small shop. The second type of rifling cutter box is the type that I chose to use because of the relative ease of fabrication. With this type of cutter box, a small ramp is advanced under the leading edge of the cutter to cause it to rise between cuts. Again, a screw is employed to control the rate of cutter advance. But instead of making direct contact with the cutter, the screw forms a stem attached to the ramp, and a small, graduated nut is retracted incrementally along the length of the screw. As the nut moves back, the ramp is allowed to penetrate more deeply into the cutter box, thereby raising the cutter.

The most difficult task of the rifling cutter box is to advance the cutter in precise increments between cuts. There are four components that work in conjunction as a cutter feed assembly to accomplish this task. These four components are the adjusting ramp, ramp retaining nut, feed adjustment nut and end-cap nut. The adjusting ramp slides into a hole drilled through the rifling cutter box and under the hook cutter. The depth of the ramp's penetration determines the height of the cutter above the surface of the cutter box. The stem of the ramp is slightly smaller in diameter than the ramp itself and is threaded to accept the ramp adjusting nut and end-cap nut. The ramp retaining nut is drilled through at the same diameter as the major diameter of the ramp stem's threads. When the assembly is installed in the rifling cutter box, the retaining nut forms a positive stop against the ramp and retains it within the cutter box. The threaded stem is free to slide back and forth through the retaining nut to raise/retract the cutter. The feed adjustment nut determines the effective length of the adjusting ramp stem and, therefore, the depth of ramp penetration into the cutter box. Retracting (unscrewing) the feed adjustment nut along the length of the threaded stem increases the feed of the cutter above the cutter box surface when the adjusting ramp is moved forward under the cutter. The end-cap nut provides a convenient handle by which to push/pull the adjusting ramp back and forth in the rifling cutter box.

Before attempting to fabricate any of the rifling cutter box components, take a bit of time to think about what size the various components need to be. The diameters of the pieces that comprise the cutter feed assembly are largely determined by the diameter of the barrel's bore. When determining exactly what these diameters will be, it's best to start with the ramp retaining nut. The *major* diameter of the ramp retaining nut threads should be as large as possible while still leaving sufficient wall thickness in the threaded portion of the rifling cutter box. This diameter will be based upon the diameter of the cutter box. Once ramp retaining nut thread pitch and diameter is established, the adjusting ramp can be designed. The diameter of the adjusting ramp itself should be just a few thousandths under the *minor* diameter of the threads on the ramp retaining nut. By using this size as the ramp diameter, you will be able to drill the hole through the rifling cutter box with the appropriate tap-sized drill. The major diameter of the threaded stem of the adjusting ramp should be the largest appropriate size under the diameter of the adjusting ramp. The ramp retaining nut is drilled out to the nominal size of the stem threads, or just slightly larger. An alternative method that will allow you to dispense with the retaining nut altogether is to drill the rifling cutter box from the other end to whatever diameter you want the adjusting ramp to be. Only the slightly over-sized hole for the ramp stem will penetrate all the way through the cutter box. The adjusting ramp can then be inserted from the back end of the cutter box. This simplifies construction a little and allows the use of a larger diameter ramp, but it will require you to remove the rifling cutter box from the pull-rod in order to remove the cutter feed assembly for cleaning. It's probably not worth it unless you're making a cutter box for small calibers and absolutely *require* a little extra ramp diameter.

The body of the rifling cutter box must be fairly long in order to support the cutter as the cutter box enters the barrel blank and then exits it at the other end. The reason that it needs to be longer than you may expect is that it absolutely must be at least one thousandth of an inch under bore size to traverse the bore freely. This makes the extra length imperative so that the force of the cut can't tip the cutter box and allow the cutter

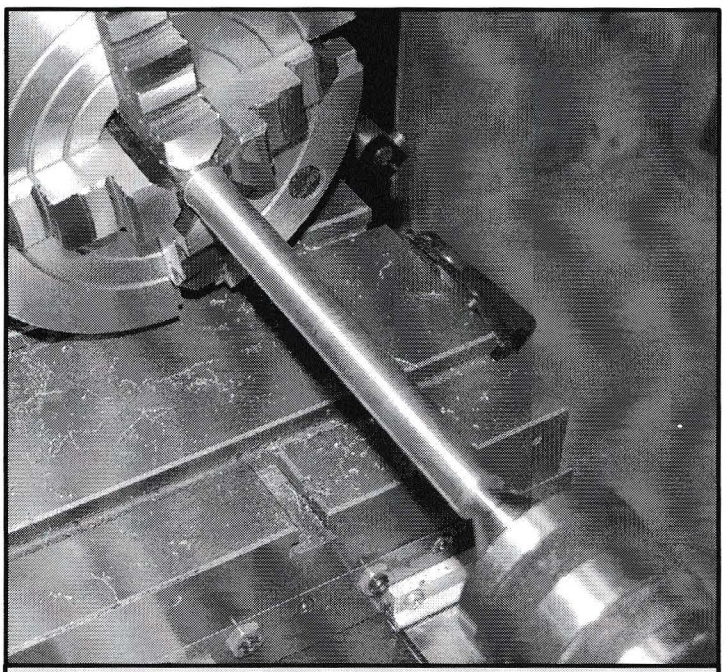
to slide into the bore without biting. Do not, for any reason, try to rifle a barrel with a short cutter box. The very first cutter box I ever made was too short. Every time that the box was drawn into the barrel, contact between the barrel blank and the cutter would force the cutter box to tip slightly. This tipping allowed the cutter to skip instead of cutting as it entered the bore. Further down the line, when the full length of the cutter box had entered the barrel, the pressure would finally press the cutter into the steel hard enough that it would actually begin to cut. I saw what was going on and tried to compensate by feeding the cutter out more than the recommended .0001" per pass, and this did get the cutter to bite right from the beginning. However, it also dramatically increased the pressure of the cut once the rifling cutter box was fully inside of the bore. The extra pressure made a very rough cut and it also significantly increased the wear on the top of the cutter, forcing me to sharpen the cutter after a mere one or two passes. The situation only got worse as the process proceeded. I eventually gave up before the rifling was even .003" deep and threw both the barrel and the rifling cutter box in the scrap heap. I learned from my mistake and made my next cutter box longer, and it's still making barrels today. The cutter box length that I finally settled on as entirely adequate is 5". Unlike most other aspects of my tooling, this is one dimension that will not scale down if you intend to make small-caliber barrels. I don't care if you're making 17 caliber varmint barrels; use a cutter box that is at least 5" in length. This bears repeating: *do not, for any reason, try to rifle a barrel with a short cutter box*. I promise that you will regret it if you do.



The rifling cutter box is profiled in short increments.

When turning such a long workpiece (relative to diameter) on the lathe, it is wise to make the cut in short increments. If the entire length of the cutter box is turned all in one go, the center of the workpiece will bow away from the lathe bit and the end result will be a football-shaped finished product. I follow the basic rule of turning only a length of workpiece that is three times the final diameter. Since my smallest barrel bores measure slightly more than ½", I can turn the outside diameter of the rifling cutter box 1½" or so at a time. The first increment of the cutter box's length can be cut unsupported, but after that, the tailstock center should be used to provide full support of the workpiece for each successive cut. The four-jaw independent chuck is used to hold the workpiece so that it can be precisely centered after each advance in length beyond the jaws of the chuck. For reasons that will become apparent later, I leave the diameter of the cutter box .003" to .004" over bore size at this stage. After the workpiece is cut to this diameter, it is cut off of the raw bar for further

operations. Although both ends of the rifling cutter box should definitely be faced square, it is not necessary to break the sharp edge around the perimeter of the face. Sharp edges help to keep chips from getting between the barrel blank and the cutter box. If the rifling cutter box is precisely aligned with the bore of the barrel blank during setup for the rifling operation, the cutter box will enter the bore smoothly, even with a sharp leading edge.

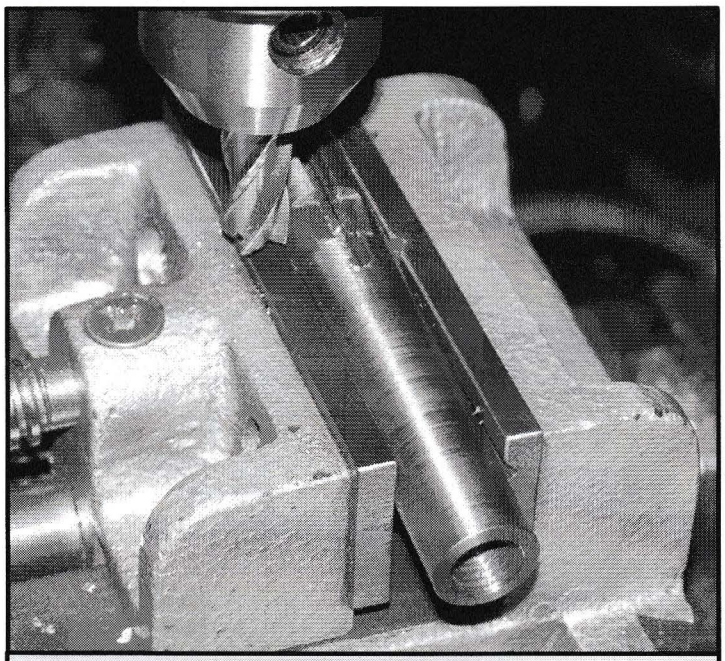


The rifling cutter box is now profiled full-length.

After being cut off and faced, the cutter box is then drilled out to accept the adjusting ramp. Remember that this diameter can be no larger than the tap-size drill for the threads of the ramp retaining nut. This is a simple, straightforward procedure, but the hole should be drilled out with incrementally larger drills, starting with a ⅛" drill bit. The reason to proceed in stages is that you want the drilled hole to be as straight as possible. There will be a long, threaded shank sticking out of the back end of the adjusting ramp with various accoutrements stationed along its length. You do not want this apparatus to be off-kilter in such a way that it could possibly make contact with the bore of the barrel that you have oh-so-carefully reamed butter-smooth. Once the bore of the cutter box is drilled to tap diameter to a depth of 3½", threads are cut for the ramp retaining nut to a depth of about ¾". The rifling cutter box can then be flipped around in the lathe so the other end can be drilled out in the same fashion. The back end of the cutter box is drilled to a diameter larger than the adjusting ramp. This is done so that a spring-loaded plunger can be installed. During use, this plunger will make contact with the rear surface of the hook cutter to keep it firmly pressed down against the adjusting ramp. In order for this to work properly, the plunger must make contact with the cutter *above* the cutter's pivot point. For this reason, the plunger diameter should be as large as possible without leaving the walls of the cutter box excessively thin in this section. I like to leave the cutter box walls about 1/16" thick in this area. The usual caveat applies again here. If you're making smaller calibers than I do, the cutter box wall may have to be thinner in this section. The plunger section of the cutter box is drilled to a depth of 1⅝". This allows the drill to break through into the section that was drilled from the other end and ensures that the plunger will be able to bear fully on the cutter without butting against the shoulder formed between the two disparate bore diameters. Before removing the cutter box from the lathe, there is one final step to perform that will pay dividends when milling the slot for the cutter and drilling the cross-hole for the cutter pivot pin. I drag the tip of my lathe bit across the face of the cutter box using the cross-slide to create a perfectly straight, perfectly centered scribe line. The bit only has to touch

the workpiece just enough to mark the steel, not hard enough to actually cut the workpiece or damage the bit with excessive lateral pressure. This reference line is used to precisely index the pivot pin hole at 90° to the milled slot.

Once turned to size, the rifling cutter box is positioned in the mill vise to cut the slot for the cutter. A square is used to ensure that the line scribed on the cutter box face is vertical. The location of the slot for the cutter along the length of the cutter box will be determined by the size and geometry of the cutter itself. I make my cutters 1½" long and the actual cutting surface is located ¼" from the end of the cutter body. The goal when milling the cutter slot is to place that cutting edge just about dead-center in the rifling cutter box. This placement ensures that there will be a sufficient length of cutter box in the barrel's bore to fully support the cutter as it enters and exits the bore. Because of my earliest experience with a too-short cutter box, I hedge my bets a little and actually place the cutting edge of my cutters at 2.85" from the back end of the cutter box. This placement has worked well for me, but a dead-center position (at 2.5") would likely work just as well. Once the location of the cutter has been established, the rifling cutter box is drilled with a ⅛" drill (my hook cutters are ⅛" wide) and then the slot is milled from that point with an ⅛" end-mill. After the slot is milled, the cutter box is repositioned in the vise at an angle of 5° to cut the chip relief slot behind the cutting edge. This slot is cut with a ⅜" end-mill to a depth of 1/16" at the furthest point from the cutting edge. Cutting the chip relief slot at 5° allows me to use a square stone to sharpen the cutter with the recommended 5° rake angle for cutting steel. Even though each rifling cut is only .0001" deep, that depth of cut at ⅛" wide over a length of 32" produces enough chips to completely fill the chip relief slot. If you're planning to scrape more steel than that on each pass, you will definitely need a more spacious chip relief slot.



This is the setup for milling the chip relief slot. Note that the slot for the hook cutter has already been milled.

The final machining operation that needs to be performed on the rifling cutter box prior to heat-treatment is drilling the cross-holes for the cutter pivot pin and the attachment pin that will join the cutter box to the pull-rod. I reposition the cutter box in the vise by rolling it 90° and using a small precision level held on the index mark that was scribed on the end earlier. When this scribed line is level, I know that my pivot pin hole will be exactly perpendicular with the cutter slot. The bottom edge of the cutter has to lie above the centerline of the rifling cutter box so that the adjusting ramp will be able to slide beneath it. Obviously, this means that the pivot pin must also lie well above-center.

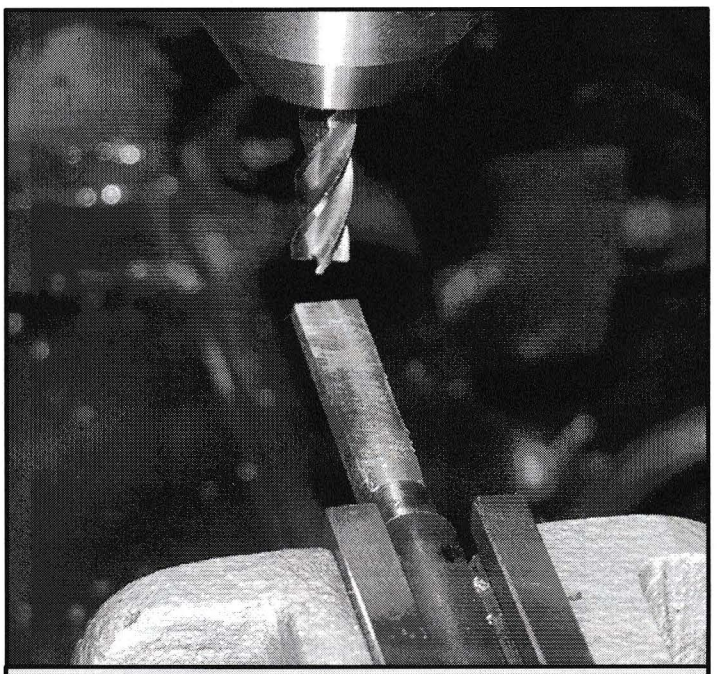
In order to accomplish this, the drill has to bite into the side of the cutter box instead of coming down squarely on the top. A normal twist drill will not be able to do this, so a center-drill must be used to drill a pilot hole. Actually, I start with a #1 center-drill to mark the spot and then finish with a #4 center-drill (pilot tip diameter ⅛") to finish by drilling as deeply as possible before the 60° portion of the cutting edge makes contact with the workpiece. This is deep enough to get past the rounded side of the cutter box so that the normal twist drill will be able to stay on course. The pivot pin passes through the cutter box in a location that intersects the top of the bore for the adjusting ramp. Because of this, drilling the pivot pin hole is an interrupted cut all the way through. This represents about the worst scenario for trying to drill a straight hole with a conventional twist drill, so the drilling operation must be performed slowly and carefully. Just lightly peck away at the steel until the hole is complete or the hole will go crooked and/or the drill will snap. Drilling the cross-hole for the attachment pin is comparatively easy because it can be placed smack dab in the center of the rifling cutter box. With the cutter box in the same setup, center the cutter box under the drill spindle at the location where you want the attachment pin to be and drill straight through. This operation is no different than drilling any other cylinder through its diameter.

The next step is to fabricate the components of the cutter feed assembly. The adjusting ramp is turned to diameter in the lathe. The diameter of the ramp is the diameter of the drill that was used to cut the bore through the cutter box to a tolerance of -.001" to -.002". The length of the ramp is determined by the position of the cutter in the rifling cutter box and the length of the threaded portion of the ramp retaining nut. Measure from the front (face that mates with the retaining nut) of the cutter box to the nearest end of the cutter slot, and then subtract the length of the threads on the retaining nut. Add .1" to this measurement and this will be the length of the ramp body. The extra tenth of an inch ensures that the ramp is too long to be pulled completely out from under the cutter when the ramp is retracted. Once the ramp is turned to diameter at this length, it is placed in the mill vise to cut the slope. The exact angle of the slope will be determined by the number of graduations you intend to use on your feed adjustment nut and the pitch of the threads that you will cut onto the stem of the adjusting ramp. Keep in mind that the fewer graduations there are on the feed adjustment nut, the shallower the ramp angle must be to raise the ramp a mere .0001" per graduation. Additionally, fewer graduations will require a longer adjusting ramp and stem to provide a given amount of upward feed to the cutter, and there's not much room inside the cutter box to work with. I use ten graduations on my feed adjustment nuts. This allows fine enough control of the cutter without making the length of the cutter feed assembly too long to fit inside the length of the cutter box. Using ten graduations also makes determining the angle of the ramp a snap.

Calculating the ramp angle to be used with a ten-division feed adjustment nut is done by determining the tangent of the angle needed. The tangent will be equal to the vertical travel of the cutter divided by the horizontal travel of the ramp needed to cause that amount of rise. With ten increments on the feed adjustment nut that each raise the cutter .0001", each full turn of the nut (full thread of the stem) will raise the cutter .001". This means that the number of threads per inch will correspond exactly with the number of thousandths of an inch that the cutter will rise per inch of ramp travel. So, to calculate the slope of the ramp used in conjunction with a ten-division feed adjustment nut, simply multiply the thread pitch by .001. For instance, if you thread the ramp stem to 40 threads

per inch, the tangent of the proper angle to raise the cutter .0001" for each of the ten increments is .040, and this implies an angle of 2.29°. Pretty neat trick, huh? I thought so too after I calculated the slope of my first ramp the hard way (dividing .001" by the reciprocal of the thread pitch) and then had this epiphany when I noticed the similarity between the thread pitch and the calculated tangent.

The actual slope of the ramp does not need to extend the full length of the ramp-diameter section of the component, which measures about 1.6" in length for my rifling cutter box design. My cutters are 1½" long and the pivot pin hole is located .2" from the back end of the cutter, resulting in an effective cutter length of 1.3". The cutter body has the same depth along the full length, meaning that the bottom of the cutter is parallel with the top. In order to maximize the total amount of vertical cutter feed possible, the leading edge of the ramp is made to hold the hook cutter body flat (parallel with the rifling cutter box).This arrangement precludes the possibility of feeding the ramp any deeper into the rifling cutter box than the cutter pivot pin. At this depth of feed, the bottom of the hook cutter and the surface of the ramp will be parallel and in full contact for the entire effective length of the cutter. All of this, in turn, means that there is no reason to cut the slope of the ramp to a length longer than 1.35" or 1.4". Since the section that is full ramp diameter is 1.6" in length, there is a short, full diameter round section left after the slope is cut. *Do not continue the cut for the ramp slope through this section.* The ramp stem is left uncut (full raw workpiece diameter) until after cutting the slope so that there will be plenty of surface area for the mill vise to grip when milling the ramp. After cutting the required slope in the mill, the adjusting ramp is returned to the lathe to cut the stem to diameter and thread it. And that short, round section that is left over after cutting the slope is the only surface available for the lathe chuck to grip.

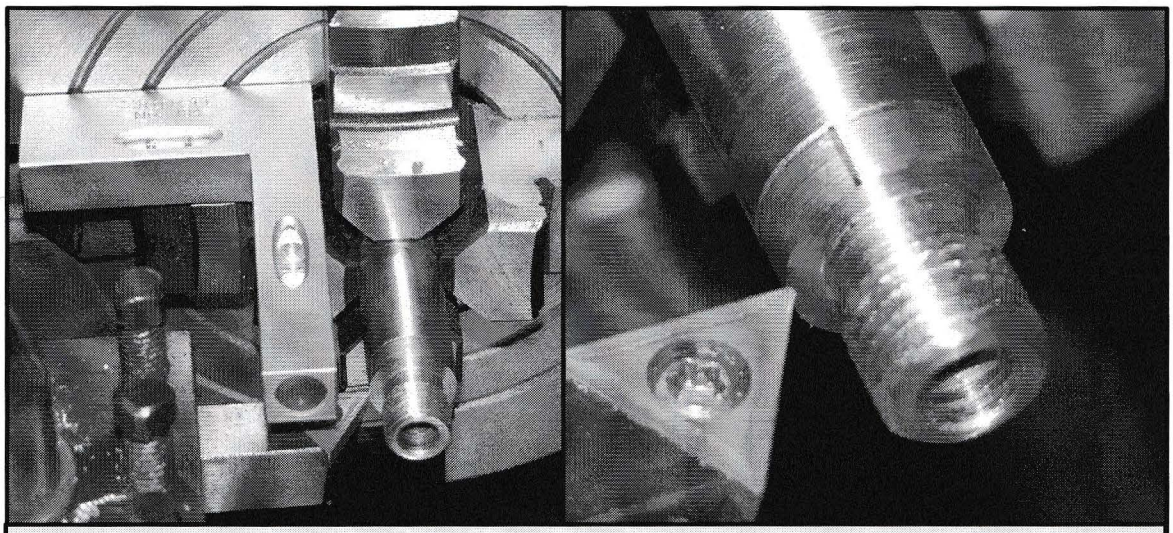


The ramp is milled after profiling. Note that the stem has not been turned and threaded so that the vise can hold it firmly.

The adjusting ramp's angled surface should be milled to a depth no more than half the diameter of the ramp body. During the rifling operation, the hook cutter is raised for sharpening by retracting the ramp until it butts against the ramp retaining nut. The ramp is then rolled over so that the hook cutter rests on the round portion of the ramp, thus raising it high enough to be sharpened without changing the setting on the feed adjustment nut. If the angle of the ramp is milled past the halfway point, the hook cutter will be able to slip past the ramp as it rolls and fall too deeply into the rifling cutter box. Since the cutter is being pushed downward by the plunger behind it, the only way to

remedy the situation is to disassemble the cutter box so that the cutter can be raised enough for the ramp to slide back under it. After the milling operation is complete, the ramp surface must be draw-filed and stoned, with strokes that are *parallel to the length of the ramp*, to near-perfect, mirror smoothness. Remember, the ramp is designed to accurately raise the cutter .0001" at a time, so it won't do to have transverse tool marks .001" deep in its surface.

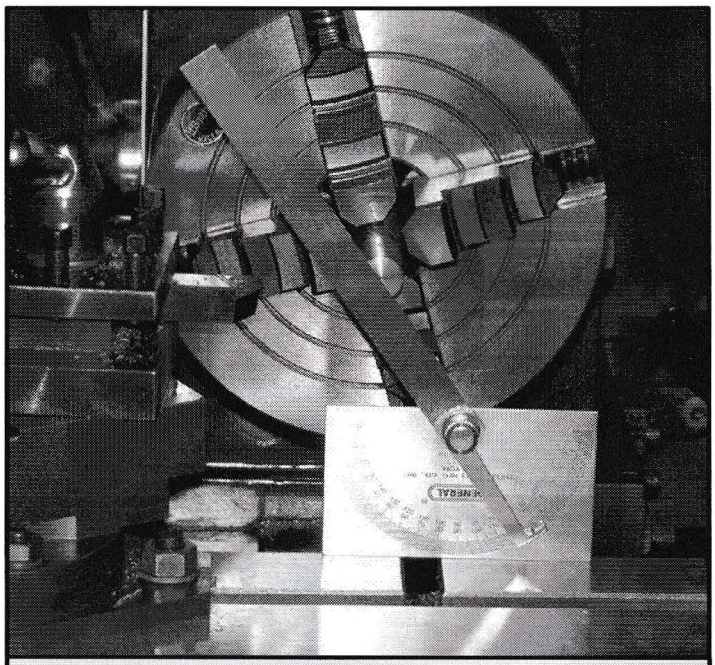
The adjusting ramp stem must be long enough to carry the adjusting nut and end-cap nut, penetrate the ramp retaining nut, and still have enough length left over to allow the adjusting ramp to slide fully under the cutter. I make my feed adjustment nuts and end-cap nuts each .5" long. The ramp retaining nut is .55" long with a .4" threaded section and a .15" round section. And, as discussed above, my ramps need to be capable of traveling at least 1.3". This means that the ramp stem must be at least 2.85" long. I make mine 3" long just to be sure. After the stem is turned to the required major diameter of the intended threads, the stem is threaded while still mounted in the lathe chuck. The threads can, but do not have to, extend for the full length of the stem. The short section of the stem that will lie inside the ramp retaining nut when the ramp is fully withdrawn from under the cutter can be left unthreaded.



A precision level is used to index the four scribed marks on the retaining nut in conjunction with the four-jaw chuck. One of the scribe marks can be seen in the photo on the right.

The ramp retaining nut, feed adjustment nut and end-cap nut should not be capable of touching the bore of the barrel blank. I turn the diameter of these components to .01" to .03" under bore diameter, depending upon the caliber of barrel involved and my arbitrary inclination at the time. Once again, consider the size of my tooling. If you're making a rifling cutter box for 22 caliber barrels, it would be acceptable and probably advisable to stop at about .005" under bore diameter in order to avoid making the components too small and fragile. The feed adjustment nut and end-cap nut are drilled and tapped to accept the threaded ramp stem. As discussed before, the ramp retaining nut is .55" long with a .4" threaded section. The ramp retaining nut is scribed with four index marks with which the index marks on the feed adjustment nut are aligned when advancing the ramp to raise the cutter. I like to scribe four index marks so that I can be sure that at least one of them will be easy to see when the rifling cutter box is in position

to adjust the ramp feed depth, no matter what rate of twist is being used to rifle the barrel. The index marks are easy to scribe. After all other operations on the ramp retaining nut are complete, I lay a small level on the closest horizontal jaw of the four-jaw chuck to align the nut. The lathe bit is then advanced .002" beyond the final cut on the outer perimeter of the nut and the carriage is fed towards the headstock to scribe a thin line on the retaining nut. This process is repeated three more times by leveling each successive chuck jaw and scribing a line at each location. The last step in fabricating the ramp retaining nut is to drill a shallow, $^{5}/_{64}$" hole into the perimeter of the retaining nut's collar. This allows me to use a drill bit shank or other pin for leverage to loosen and remove the retaining nut when the rifling cutter box needs to be cleaned.

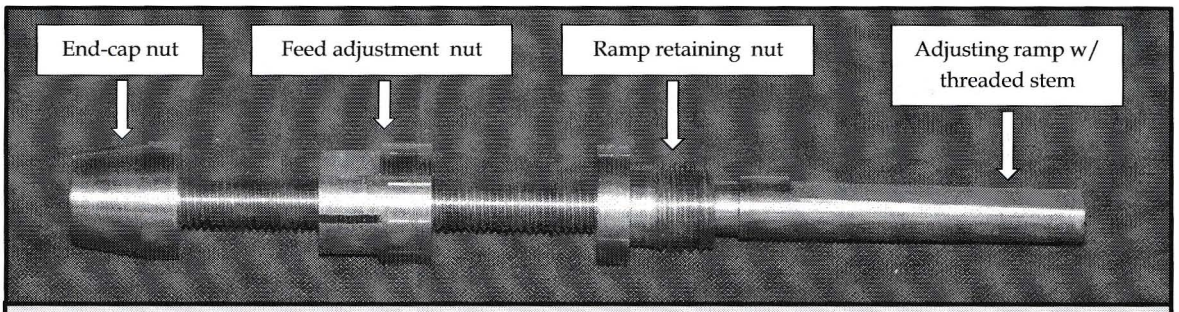


An adjustable protractor is used to index the ten divisions of the feed adjustment nut.

The process of indexing the feed adjustment nut to scribe its ten divisions is a bit more involved. To do this, I scribe a line across the face of the adjustment nut. An adjustable steel protractor is used to index the face-scribed line at the proper angle for each index mark. The outer perimeter is then scribed by the same method used to scribe the ramp retaining nut. For ten divisions, there will be an angle of 36° between each successive index mark. The next operation on the feed adjustment nut is to mill two opposing flats on its sides. These flats are not milled to make the nut easier to grip. Their purpose is to thin the cross-sectional area of the adjustment nut so that its end can be squeezed ever so slightly in the vise. This makes the threads of the nut grip the threaded ramp stem firmly so that the nut will not move inadvertently when the rifling cutter box is spun through the bore. This would advance or retract the adjusting ramp instead of keeping it on the desired setting. I mill the flats to a depth that will leave the walls of the nut $^{1}/_{16}$" thick over the major diameter of the ramp stem. The final step is to split the upper section of the feed adjustment nut. Again, this is to facilitate the slight squeezing of the component in the vise. This operation can be performed with a slitting saw while the nut is in the mill vise, or it can be done later with a hacksaw. If you want to use a hacksaw, the best way I have found to hold the nut is to grip a screw with the appropriate threads in the vise jaws with a bit of threads exposed above the jaws. The feed adjustment nut is then screwed down hand-tight against the upper surface of the vise jaws. If you know what you're doing with a hacksaw, this is a sufficiently sturdy setup for slitting the adjustment nut. The feed adjustment nut is the one tooling component that definitely needs to be made out of low-carbon steel. I use 1018 for this part. I tried making a feed adjustment nut out of a scrap of 1144 once just to

see what would happen when I tried to squeeze it down in the vise. What happened was absolutely nothing. The medium carbon content and work-hardening of the steel prevented me from squeezing it at all. I finally got really serious and used my full body weight and all of my strength on the vise handle. Lo and behold, something finally happened; the nut snapped in half. Medium carbon steels are designed to retain their shape under stress right up to their yield strength. So when you need to cold-form steel, it's best to stick with the soft stuff.

There are no special steps required to fabricate the end-cap nut because it has no critical role to fulfill. It's just a handle. After turning this component to diameter, drilling and tapping, I cut a 10° slope on the upper .35" of the nut. This is done by reversing the direction of the lathe spindle, setting the compound rest to 10° and cutting the slope on the back side of the workpiece. The slope will indeed provide a bit of protection for the bore of the barrel blank if the rifling cutter box somehow becomes grossly misaligned, but mostly it's just for looks. When the end-cap nut is screwed onto the ramp stem during final assembly, I put a few drops of red Lock-Tite on the threads to hold it stationary when in use. If I ever need to take it off, a bit of heat from a propane torch will break the bond of the Lock-Tite.

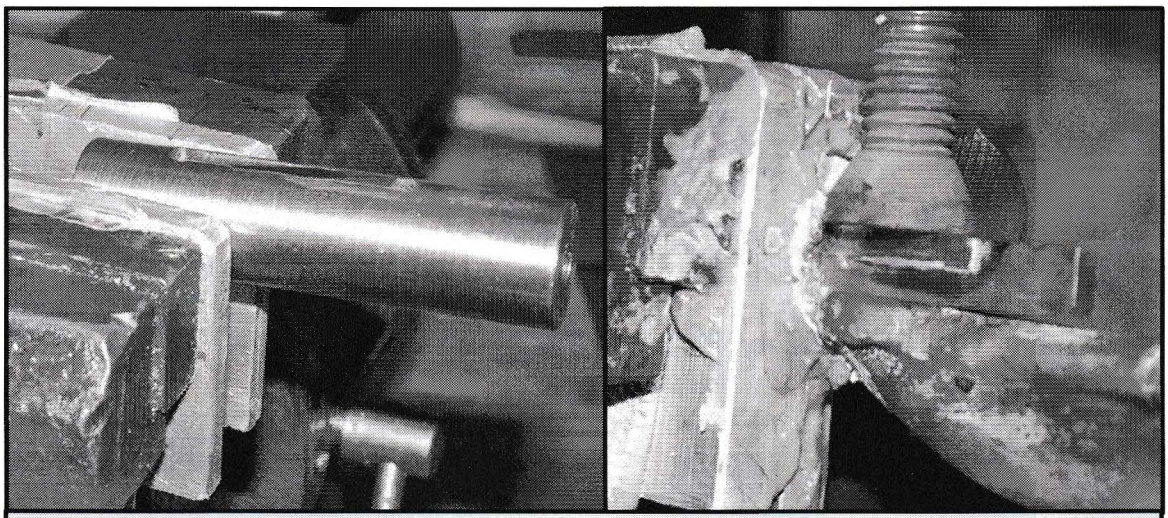


This is the completed cutter feed assembly with all components in place.

The hook cutter is made from a ⅛" square, high-speed steel cutter bit such as those used for adjustable fly-cutters. As far as the grade of steel used for the cutter, any high-speed steel will work quite well, but some grades will need to be sharpened more frequently than others. As far as edge holding qualities are concerned, T-15 steel is about ideal. However, T-15 is also very hard to wear away with a sharpening stone. To make the cutters a little easier to sharpen, I use M-2 to make my hook cutters. Edge life is pretty fair and it doesn't take more than a few minutes to hone them back to razor sharpness after they become dulled. The high-speed steel bit is cut to 1" in length and ground square on both ends. A relief angle is then stoned onto one end of the cutter blank. This angle will form the relief provided to the cutting edge during the actual machining of the rifling, and the shape to which the upper surface of the cutter is stoned will determine the shape of the rifling grooves in the barrel blank. To stone the relief at the correct angle and shape, I use a round bar of steel as a combination cutter holder and stoning guide. The bar is turned to the final groove-circle diameter of the barrel's rifling. It is then clamped in the mill vise at an 8° angle and a ⅛" slot is milled into the bar. The cutter blank is scribed at ¼" from the end that will be shaped to mark the location of the actual cutting edge. The cutter blank is then slipped into the stoning guide's slot and slid back and forth until the scribed line is flush with the surface of the stoning guide. Finger pressure is sufficient to hold the cutter in position for the stoning operation. The surface of the cutter blank can now be stoned down flush with the stoning guide to

simultaneously form the relief angle of the cutter and the shape of the rifling grooves. Use a wide stone in arcing strokes, and when the stone begins to scuff the surface of the stoning guide, the cutter relief angle is complete and will perfectly match the shape of the stoning guide (which matches groove-circle diameter).

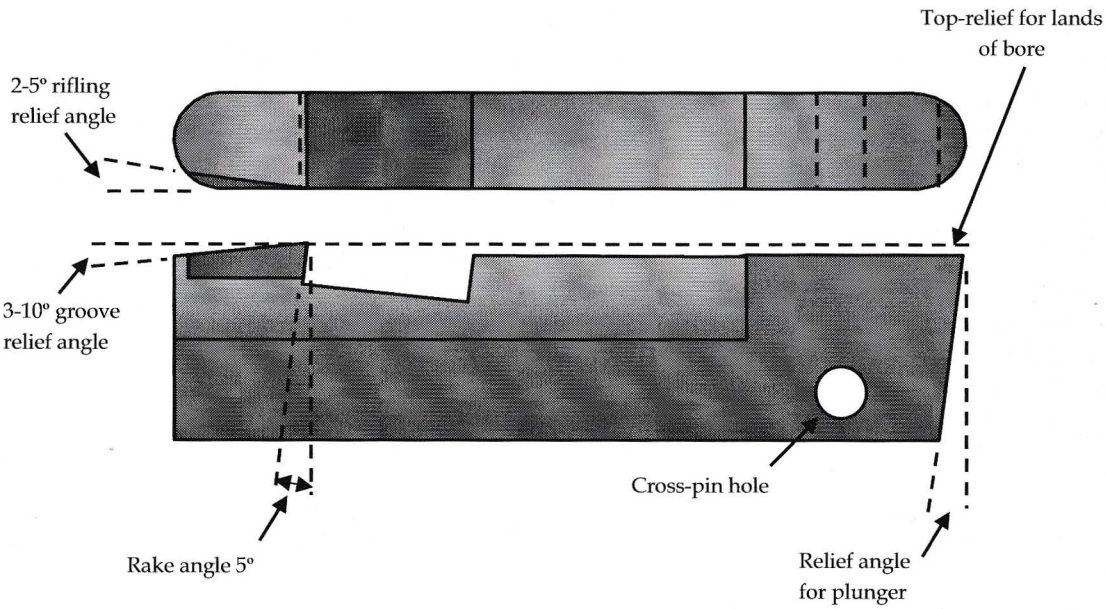
Note that I use an 8° relief angle on my hook cutters. Some references suggest using relief angles as shallow as 3° for hook cutters. I initially used this angle on mine, but I found that such a shallow angle caused the top of the cutting edge to begin interfering with the cut due to wear very quickly. I got tired of constantly reconditioning the upper surfaces of my hook cutters during the rifling operation and decided to try a steeper angle. References for most types of steel-cutting tools suggest relief angles between 5° and 10°, so I split the difference and tried the 8° angle that I currently use. Cutters with this angle have worked so much better for me than cutters with the shallow angle that I will never again attempt to use a cutter with a mere three degrees of relief. The downside of using a steep relief angle is that the upper surface of the cutter falls away from the cutting edge so much more rapidly. This means that, because the cutting edge is stoned laterally towards the back of the cutter when sharpened, the cutter will become too short to cut the rifling to full depth faster with a steep relief angle than it would with a shallow angle. In other words, the cutter will have a shorter life with a steep relief angle. However, the gains in ease of use and sharpening that are realized with an 8° relief angle more than off-set the comparatively minor inconvenience of fabricating a new cutter a little sooner than would otherwise be necessary.



On the left is the high-speed steel cutter after it has been stoned to the correct radius and relief angle. On the right, the cutter is being silver-soldered to the mild steel cutter body.

After stoning the relief angle on the hook cutter, the bit can be silver-soldered to a piece of mild steel. In the case of hook cutters for small-caliber barrels, the mild steel will be a small piece of ⅛" square-stock soldered onto the back end of the cutter. The pivot pin hole is drilled through the mild steel. But for larger calibers, a ⅛" square bit does not have enough depth to reach the lowest point on the adjusting ramp's surface. Because of the dimensions of larger rifling cutter boxes, the mild steel isn't just an easily drilled extension of the cutter. It is also a filler material between the high-speed steel cutting bit and the adjusting ramp. It is best to make the hook cutter a couple hundredths of an inch too tall at this point. It will be ground to the proper finished height later. Due to the

extreme heat required for silver soldering, I put a big gob of Heat-Stop on the cutting portion of the high-speed steel cutter during the soldering operation. I have read that high-speed steel can be heated to red-hot without losing its hardness and edge-holding qualities. Maybe some have found this to be true, but I'm not among them so I always use the paste. After the cutter is assembled into the rifling cutter box, you can measure how much too high it is and then grind the bottom of the cutter for a perfect fit. The hook cutter also needs to be made a little too long to fit in the cutter slot in the cutter box. After the high-speed steel bit is soldered onto the mild steel filler, both ends are hand ground to a rounded shape that will match the rounded ends of the cutter slot milled into the rifling cutter box. A disc-sander works well for this. As an alternative, you can also use needle files to square the ends of the slot before heat-treating the cutter box, but you will find that to be much more time-consuming than rounding the cutter ends due to the very short file strokes required.



The hook cutter is made to touch only the grooves. Several different relief angles are required to keep the cutter from coming in contact with surfaces that it should not touch. The height of the mild-steel filler and the location of the cross-pin hole will vary by caliber. The relief angle for the plunger ensures that the plunger will contact the hook cutter above the centerline of the cross-pin hole. The top relief prevents the cutter body from scouring the lands as the cut deepens and the cutter is raised.

Once the hook cutter is finished, both sides of the cutter are painted with a felt-tip marker and the components of the cutter box are assembled. Retract the adjusting ramp as far as it will go and, with a very sharp scribe, trace the outline of the chip relief slot in the cutter box onto the sides of the cutter. The hook cutter can now be removed from the cutter box so that the cutting edge can be ground out. I use an adjustable-speed Dremel tool with several abrasive discs stacked onto the spindle to *carefully* grind out the slot in the cutter at about 6,000 rpm. Stacking discs makes a wider grinding surface which provides far more control of the grinding operation than a single disc. By the same token, *do not* try to grind out the slot with a Dremel tool that doesn't have adjustable speed

settings or you will make a horrific mess of your hook cutter in about five seconds. When the chip relief slot is roughed out, a thin, diamond-coated cutting disc is chucked in the Dremel tool to make a slight undercut at the base of the 90° angle formed by the cutting edge and the bottom of the slot. This undercut ensures that the corner can't interfere with the corner of the sharpening stone when touching up the cutting edge. The diamond wheel is also used to carefully grind the relief angle on the side of the cutter. This angle should be 3-5° for centerfire barrels and 2-4° for muzzleloading barrels, depending on the rate of rifling twist. After the chip relief slot is ground out, I finish the actual cutting edge with a small, fine-grade square sharpening stone.

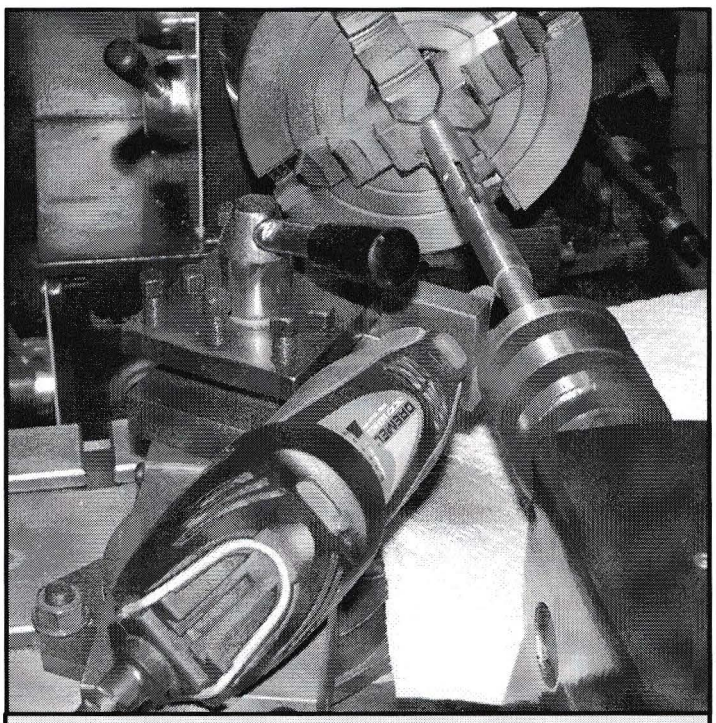
The final step in fabricating the cutter is to relieve the upper portion of the cutter in front of the cutting edge so that it won't rub and score the barrel as the cutter is advanced. To do this, the hook cutter and cutter feed assembly are mounted in the rifling cutter box. Retract the feed adjustment nut all the way until it butts against the end-cap nut. Then push the feed adjusting ramp fully under the cutter, raising it to maximum height. The portion of the cutter shank that rises above the surface of the rifling cutter box (*not* the cutting edge) can now be stoned down flush with the cutter box. This will ensure that, no matter how high the cutter is raised, it can't possibly touch the bore anywhere except where it is supposed to– at the razor-thin edge of the cutting surface. As the cutter is sharpened, the cutting edge will move back and become shorter due to the relief stoned behind the cutting edge. When the cutter finally becomes too short to cut the mustard, *do not* unscrew the end-cap nut a bit to allow the cutter to be raised higher. That will allow the shank of the cutter to rise above the rifling cutter box and score the bore of the barrel. At this point, the cutter's usefulness is at an end and it is time to make a new one.

The last components of the rifling cutter box that will need to be fabricated are the cutter plunger and the base plug. The body of the cutter plunger should be made for a close running fit inside the rifling cutter box. The length of the plunger body needs to be sufficient to prevent tilting of the plunger in the final assembly. A length of ½" has worked well for me. The plunger also has to have a stem to guide the plunger spring. I make the stem a close sliding fit to the inside diameter of the spring so that the spring will cling to the plunger stem. As for the spring itself, your local hardware store should have a suitable selection of springs. Just pick one with a length and diameter that will fit easily into the available space. The base plug for my rifling cutter boxes is made to have a light press-fit into the cutter box on one end. The other end of the base plug is made to have a light press-fit into a 4130 tube with an outside diameter under the rifling cutter box diameter. The base plug is fitted into the cutter box and pull-tube, then cross-holes are drilled through the components for two pins. If you're making small-caliber barrels, there is no reason not to use a length of appropriately sized drill rod for your pull-rod. This rod will also double as the base plug, so only one cross-hole will need to be drilled to attach the rifling cutter box.

As for heat-treatment, only the rifling cutter box body and adjusting ramp need to be hardened. I harden the O-1 rifling cutter boxes with the same procedure previously described for hardening reamers and drill guide bushings. I make my adjusting ramps out of plain old 1018 mild steel, so they have to be case-hardened. Only the ramp itself needs to be heat-treated. The stem can be left as it is. To case harden the ramp, I follow the same procedure of pre-heating and then dunking in case-hardening compound. The

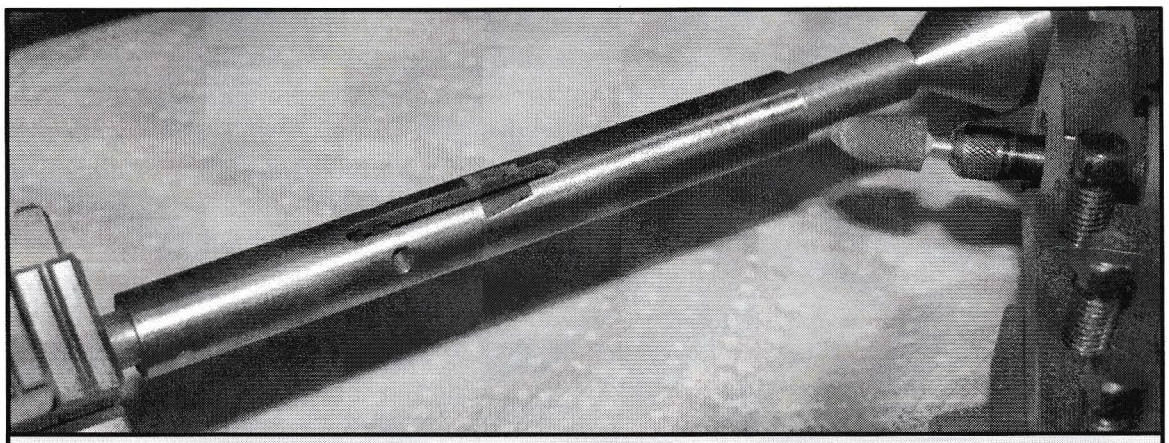
difference is that during this procedure, I am actually trying to put carbon into the steel, not just keep it from being burned out. In order to accomplish this, the steel must be kept bright-red in color and repeatedly dunked in the case-hardening compound. Build up a good layer of the compound on the outside of the steel to ensure that the carbon has nowhere to go except into the steel. I keep this up for a timed five minutes and then quench the ramp in cold water. Unlike an oil quenching medium, water will quench the steel so fast that the carbon will pop away from the surface, ensuring that the quench is very rapid over the entire surface of the part. To test the quality of my hardening treatment, I always run a needle file across several different areas of the heat-treated part. If the file manages to get a bite anywhere, the hardening treatment is repeated.

Once the heat-treatment is complete, it is time to put the finishing touches on the rifling cutter box. Unlike the deep-hole drill guide bushing and reamer, the diameter of the rifling cutter box does not have to be exact to within a couple ten-thousandths of an inch in order to function properly. An additional consideration is the fact that the rifling cutter box is long enough and has thin enough walls to warp a bit during heat-treatment. For these reasons, I grind my rifling cutter boxes to final diameter. I size my rifling cutter boxes to reamed bore diameter -.0005" to -.0015". This gives me a one-thousandth of an inch tolerance window and I made a simple grinding rig for my lathe that can hit a target this large with a little bit of care. The rig consists of a fixture for the adjustable-speed Dremel tool that is the same size as a lathe bit on one end. This end is clamped in the tool-post of the compound rest. The plastic, exterior body of a Dremel tool is threaded to accept a nut just behind the spindle. The nut serves to help keep the tool from flying apart in your hand. The business end of the tool-post fixture is drilled and tapped to accept the ¾-10 threads on the Dremel tool. The threaded bore of the fixture should be precisely on the vertical centerline of the lathe. The easiest way to mark the center is to mount a center drill (or other tool with a perfectly centered point) in the lathe chuck and then mount the fixture in the tool-post and lightly drag its face across the point of the drill by advancing the cross-slide to scribe the centerline.



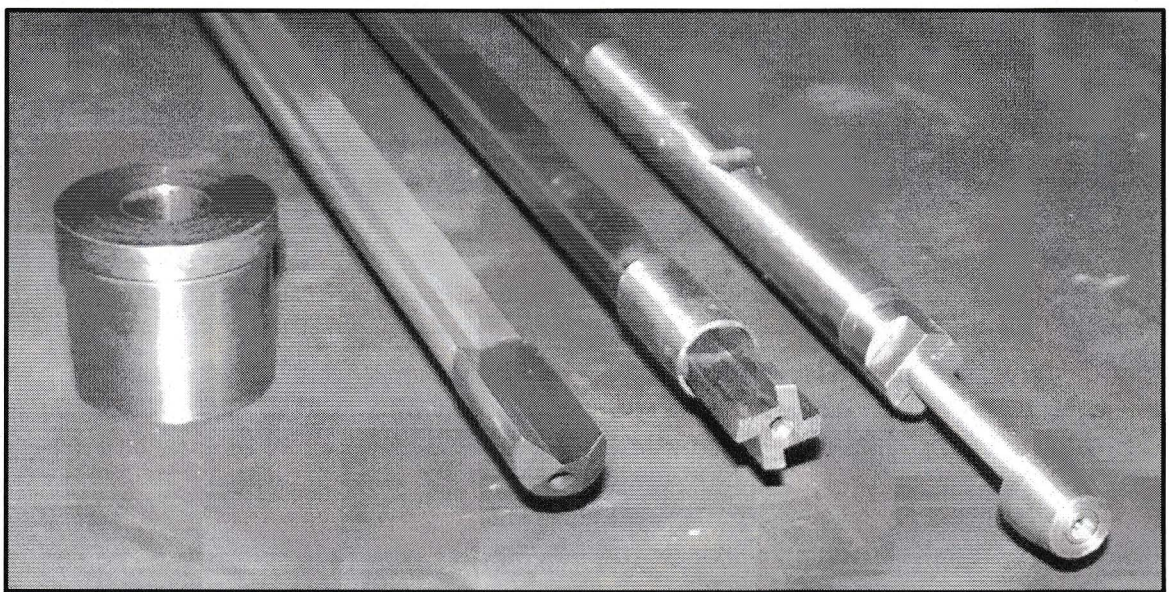
This is the setup for grinding the rifling cutter box to size.

The rifling cutter box is mounted in the lathe chuck with the help of the base plug that will eventually mount it to its pull-rod. I center the base plug in the four-jaw chuck first, then mount the rifling cutter box to it and fix it in place with a brass pin through the cross-hole. I use brass simply because it's faster and easier to file the pin down to the



Here is the heat-treated rifling cutter box after completion of the grinding operation.

surface of the rifling cutter box than it would be if it was made of steel. The other end of the rifling cutter box is supported by the tailstock with the aid of an alignment plug. This plug is threaded on one end to screw into the rifling cutter box. The other end is center-drilled to accept a live-center mounted in the tailstock. A conical grinding stone is used in the Dremel tool to grind the cutter box down to size. During the grinding operation, I run the lathe at 450rpm and the adjustable-speed Dremel at 10,000 rpm. Adjustments to the feed of the grinding stone are made with the lathe's cross-slide. Don't waste your time trying to do ultra-fine adjustments with the compound rest. There is so much give in the spindle of the Dremel tool that you have to apply a good bit of pressure to get the stone to grind instead of just glazing over. The feed rate of the lathe carriage will determine the depth of cut on each pass. A faster feed gives the stone less time to grind. When you are approaching final size, increase the feed rate to take off less material between measurements. This less than perfect control of the depth of the grinding cut is why I don't recommend trying this setup to grind reamers and drill guide bushings to size; the capability for the fine adjustments necessary to obtain the precise dimensions required



A complete set of rifle barrel tooling is ready for action after being heat-treated and sharpened.

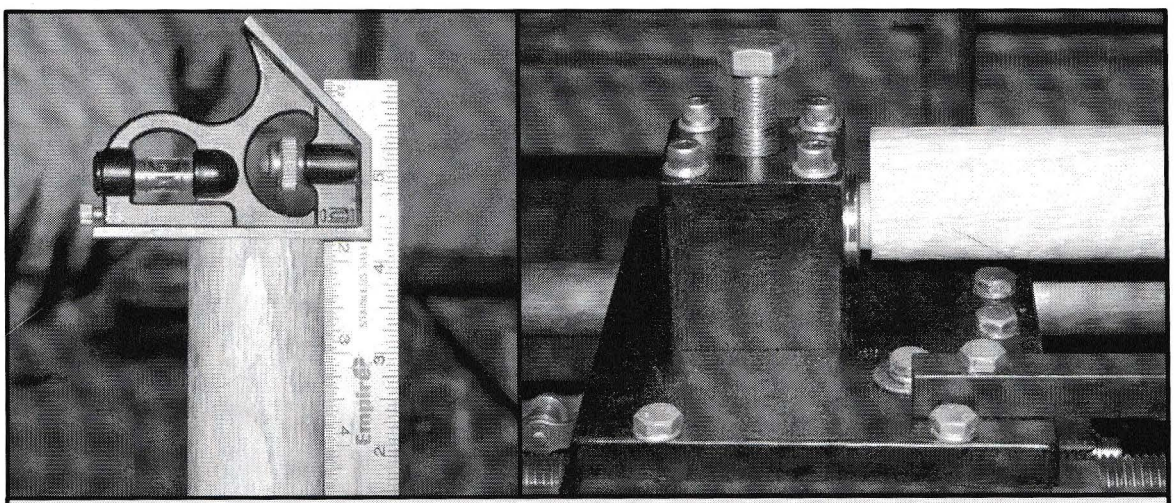
just isn't there. But with a bit of care and constant measurements, it is certainly possible to hit the one-thousandth of an inch wide tolerance window of the rifling cutter box's dimensions. After the grinding operation is complete, the rifling cutter box is finally ready to be assembled so it can start making some chips.

The Rifling Cylinder

The last tooling component that must be fabricated before you can get down to the real work is the rifling cylinder. As explained in an earlier chapter, the rifling cylinder is a round bar that has a groove cut into at a pitch that matches the desired pitch of the finished rifling. The traditional material for rifling cylinders is hardwood, usually oak. If, like me, you do not own a horizontal mill with lots of travel and a universal indexing head, this is the material you will want to stick with. The following section details the procedure I use to fabricate hardwood rifling cylinders. If, on the other hand, you do own, or have access to, the required milling equipment, there is absolutely no reason not to use that equipment to make aluminum rifling cylinders. You will find that procedure to be far faster and easier than the one that follows.

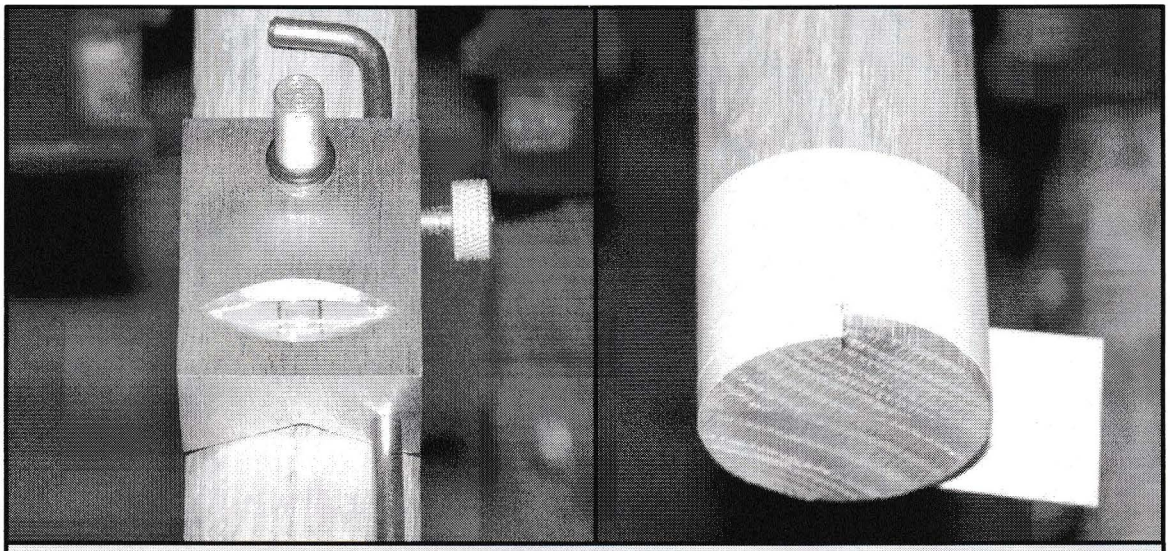
The most basic requirement for a rifling cylinder is that it must be straight. Absolute perfection is not required, so it is not imperative that the cylinder be turned on a lathe. But you do need to be a bit choosy in selecting the raw hardwood cylinder. Fortunately, oak commands a fairly high price and lumber dealers tend to take pretty good care of their higher-priced products to protect their investment. This means that there is an excellent chance that you won't have much trouble finding a local merchant with several sizes of nice, straight oak round. Do take the time to look at every specimen that he has in the size you want and pick the best one. While absolute perfect straightness isn't mandatory, you are making a precision cutting tool guide, not a handrail for a flight of stairs. You want to select the largest diameter of rifling cylinder that will fit on your machine to reduce the effect of any slight inaccuracies in the guide groove.

The rifling cylinder is cut to whatever length you need for your machine. The distance between the universal block and the rifling cylinder block on my machine is exactly 48" when the two carriages are tied together with the rifling cylinder straps. The bearing inserted into the universal block is not set to the full depth of the bearing. The



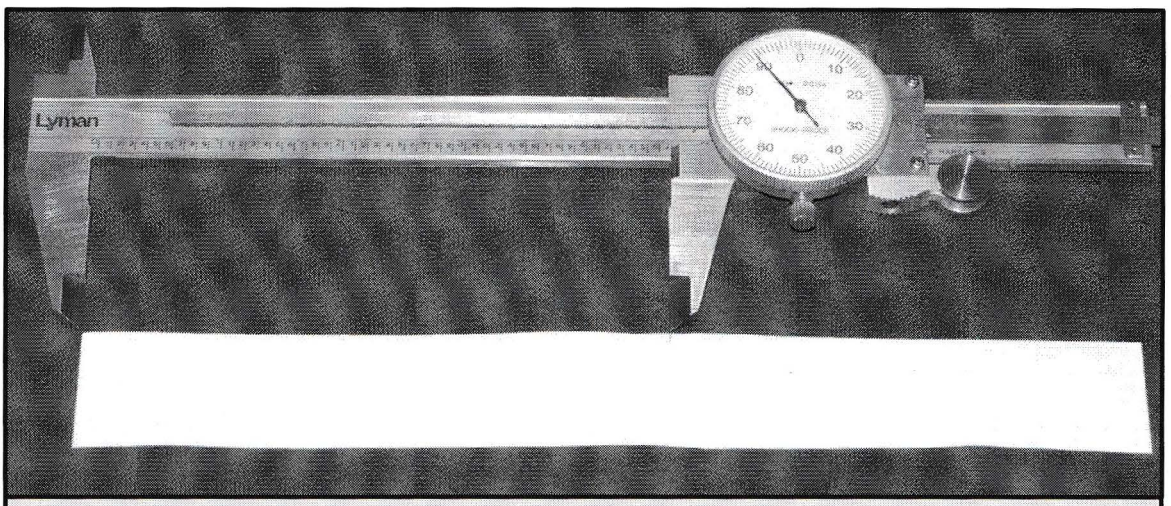
File the ends of the rifling cylinder down square until it fits snugly between the machine's carriages.

counter-bore that accepts it is only half the depth of the bearing. This was done to allow the bearing to be removed from the universal block with my fingers after the rifling operation is complete. I also use nylon washers between the bearings and the rifling cylinder. This is done to ensure that the cylinder will not rub against the outer races of the bearings when the cylinder is in use. I subtract the length that half of the universal block bearing and both washers occupy and come up with a finished length of $47^{7}/_{16}$" for my rifling cylinders. Initially, the rifling cylinders are cut to 47⅝". One end of the cylinder is filed perfectly square and then the process of filing and fit-testing begins. I file down the other end, keeping it perfectly square as I go, and periodically test the fit on the machine until the cylinder will just slide between the carriage blocks with the nylon washers inserted between the bearings and the wood. After filing the cylinder to length, the desired rate of rifling twist can be laid out. The best way I have found to accomplish this task is to wrap a length of thin, spring-steel ribbon around the cylinder at the desired pitch. The most useful spring-steel ribbon that I have found thus far is that used for 12' tape measures. The spring-steel used to make 25' tape measures is a bit too stiff and hard to bend for my tastes and, by the same token, the ribbon used to make 6' tape measures is a bit too flimsy. But, as Goldilocks would say, the 12' version is just right. I also use short sections of the same with a backing of electrical tape to layout checkering patterns



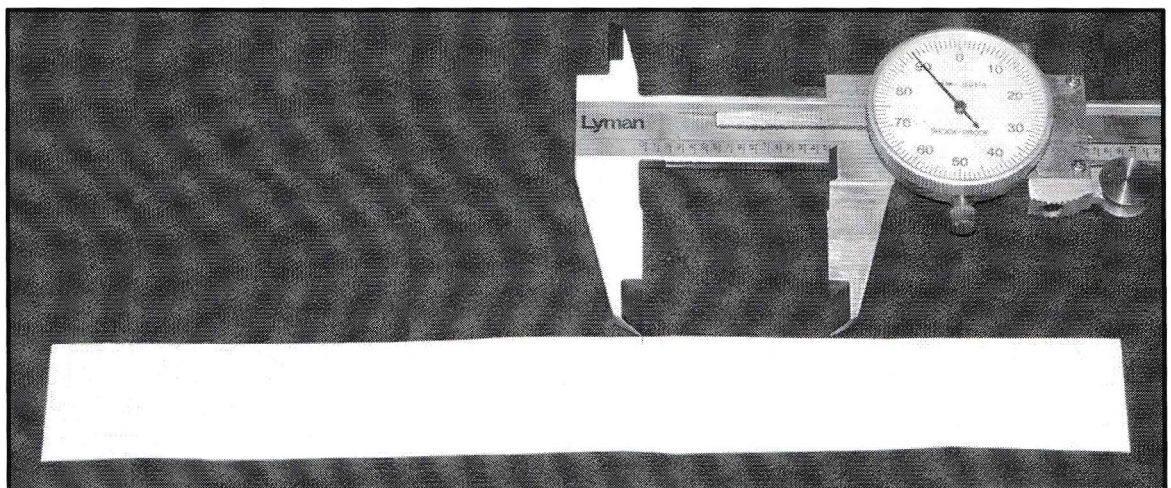
A top dead-center punch is used to mark each end of the rifling cylinder right at the very edge of the wood. One end of the cylinder is then wrapped with a strip of paper, which is marked at the exact length of the circumference.

on gunstocks. To obtain the correct twist, a top dead-center punch is used to mark a reference point on each end of the rifling cylinder. I then wrap one end of the cylinder with a strip of paper. One end of the paper is aligned precisely with the light punch mark on that end of the cylinder. After wrapping it around, a tick mark is drawn on the paper with a very sharp pencil at the point where the paper laps over itself. I then use a pair of dial calipers to measure the distance from the end of the paper strip to the tick mark and write this measurement down. This is the exact circumference of the rifling cylinder.



Dial calipers are used to precisely measure the circumference marked on the strip of paper.

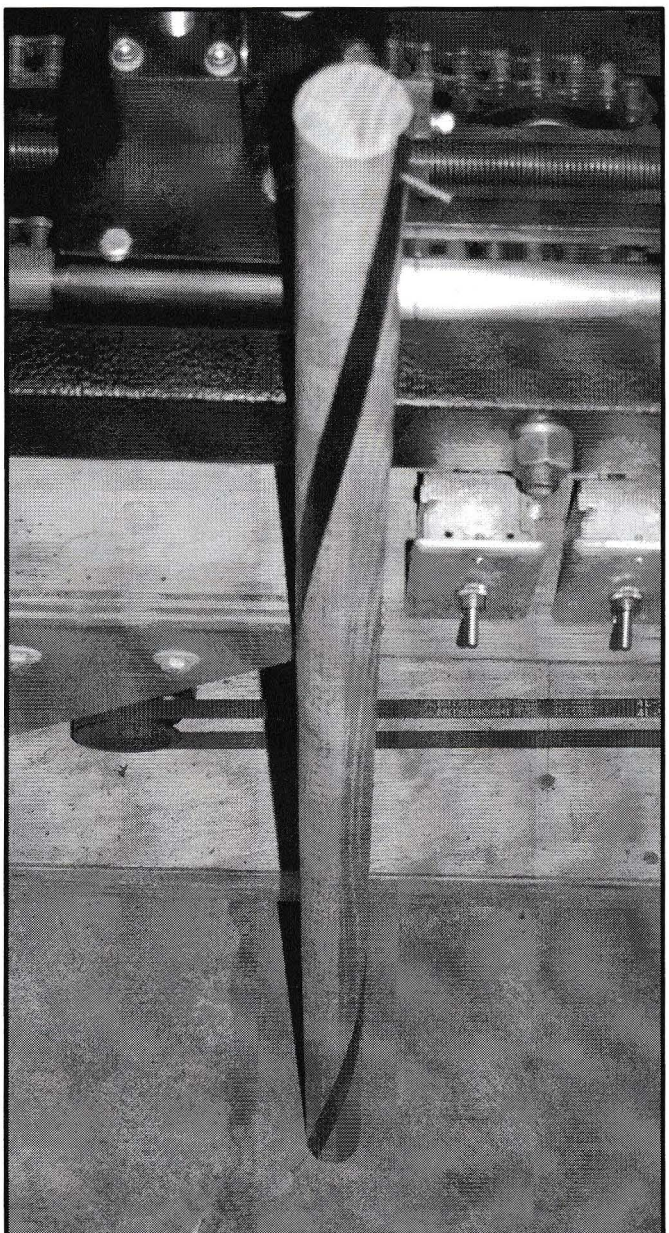
The rate of twist equates to the length of cylinder that will be required for the tape to wrap completely around the cylinder one time. This means that the length of twist can be divided by 360 to determine the distance along the length of the cylinder the tape must traverse to arc 1° around the circumference of the cylinder. Then, by calculating the length of the cylinder that remains after an even number of twists have been made, I can calculate the length of arc around the circumference at the point where the tape will run off of the cylinder when twisted correctly. Let me give you an easy example to illustrate. Suppose that I'm making a rifling cylinder with a 48" twist for muzzleloader barrels. Since my rifling cylinders measure $47^{7}/_{16}$", the tape will almost make one complete wrap around the cylinder to produce the correct rate of twist. The tape will run off of the cylinder $^{9}/_{16}$" (.5625") prior to making a complete wrap. If my cylinder is a perfect 1.500" in diameter (which it never is), then the circumference will be 4.712". The portion of the circumference occupied by one degree of arc will be .01309". To determine how many



The calipers are then used to mark the calculated distance beyond the tick mark representing one full wrap of the cylinder. The paper is then wrapped around the cylinder again and this second mark is transferred to the wood. This is the mark that the edge of the tape will align with when the twist rate is correct.

degrees of arc are represented by the cylinder's length of 47.4375", I divide this measurement by the length of twist, in this case 48", and multiply by 360. The answer is 355.78°, which leaves an arc of 4.22° that the tape *will not* traverse. So I multiply 4.22° by my calculated .01309" per degree to determine that the tape will run off of the cylinder approximately .055" *short* of making a full wrap. Now I can go back to my strip of paper and make another tick mark that is .055" *short* of the first tick mark that represents the full circumference. The paper strip is then wrapped around the cylinder as before and the very end of the cylinder is marked with a pencil at the location of the second tick mark.

Easy, right? Actually, it's a lot harder to explain than it is to do. You'll see what I mean when you make your first rifling cylinder. But what if you're making a cylinder with a faster twist? For instance, the illustrations provided in these pages are of a cylinder with a 36" twist that wraps all the way around the cylinder and then some. In this case, dividing the length of cylinder by the twist rate gives me a figure of 1.3177. The digits I'm interested in are to the right of the decimal because they represent the fraction of the circumference that the tape will traverse *after* making one complete wrap (the complete wrap is represented by the "1" to the left of the decimal). Multiplying .3177 by 360 gives me a figure of 114.37°. Multiplying this by my constant for length of arc per degree yields an answer of 1.497" (for a cylinder diameter of exactly 1.500"; again, this is never the case, hence the slightly different measurements in the illustrations). This is how far *beyond* the first tick mark on the paper strip my second tick mark needs to be to give the tape the correct twist.

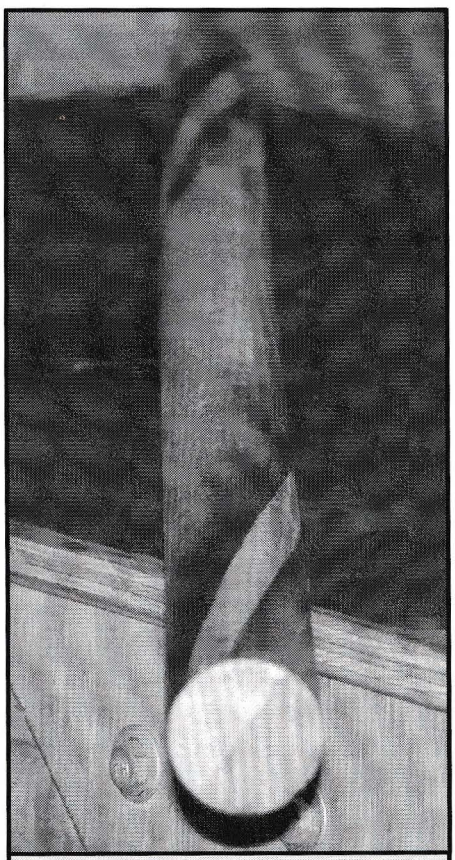


The tape is stretched and tacked in place on the cylinder.

At this point in the process, both ends of the rifling cylinder are marked to precisely represent the desired twist rate. Before wrapping the tape around the cylinder, I always sand the wood down to 300 grit. This ensures that no wood fibers are sticking up above the cylinder's surface to snag the tape and prevent it from wrapping

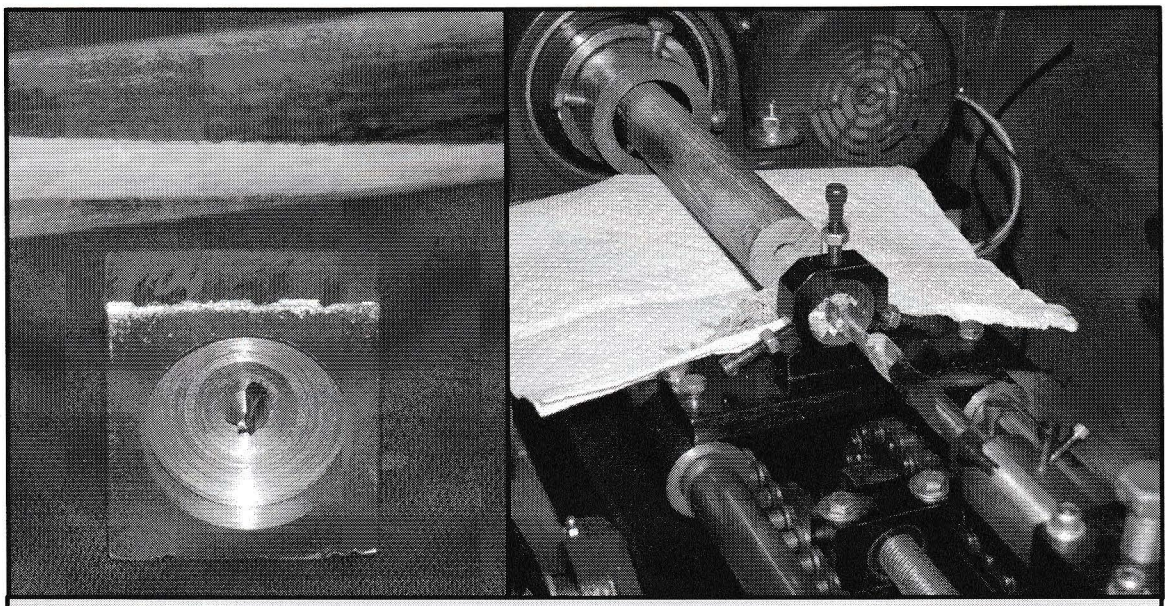
properly. Once the cylinder is smooth, one edge of the tape is aligned with one of the marks on the cylinder and the tape is tacked in place, *concave side down*, with a small nail. Make absolutely certain that the nail goes deep enough to hold under some pretty serious tension. I then stand the cylinder vertically on the shop floor with the tacked end of the tape down to prevent gravity from adding to the frictional forces between the tape and cylinder. The tape is then wrapped around the cylinder and pulled as tight as I can possibly get it. Standing the cylinder vertically helps ensure that the tape will not lag behind at any point along its length when stretched. While stretched tight, the edge of the other end of the tape is aligned with the second tick mark and tacked into place. Do not, under any circumstances, lay the cylinder down flat or touch the tape. This is no time to risk messing up a good thing. At this point, I very carefully carry the cylinder outside and mark the location of the tape with a can of spray paint. I don't even attempt to trace the edge of the tape with a pencil because that would certainly result in disturbing the tape and ruining the layout of the cylinder. After the location of the indexing groove is marked, let the cylinder stand in place (don't even breathe on it) until enough time has passed for the paint to dry completely, then wait a little longer. When you simply can't stand the suspense anymore, go ahead and remove the tape. The cylinder should now be sporting a perfect helix pattern around the circumference of its length.

I have checked, double-checked and then triple-checked just to be sure and, so far, this technique has never failed to index the twist rate with anything less than total precision for me. But there is probably a limit to the usefulness of the technique. As the twist rate gets faster and faster, the number of times the tape has to wrap the cylinder over a given length will continually increase. Eventually, the friction between the tape and the cylinder will prevent you from pulling it uniformly straight. I have used this method to index twist rates as fast as 36" with good results. I do not know how much faster the twist could be made before things begin to go awry, so proceed with caution and check the accuracy of your layout thoroughly if you choose to try this technique to produce cylinders with a more aggressive twist.



The twist is permanently marked.

Once the correct rate of twist has been marked on the rifling cylinder, the holes for the axles need to be drilled. I made a simple drill guide bushing to locate the holes in the exact center of each end of the cylinder. The guide is made of a 1" thick by 2" square block of steel. It is bored to a depth of ½" to a diameter of 1½" (for a snug sliding fit on my rifling cylinders) and there is a hole drilled all the way through that is sized to snugly fit a #4 center-drill. The drill guide is pressed over the ends of the cylinder and each end is center-drilled. Center-drilling is all I do by hand. Since I now have a very accurate drilling machine, I see no reason to drill the axle holes to full depth with a hand drill.



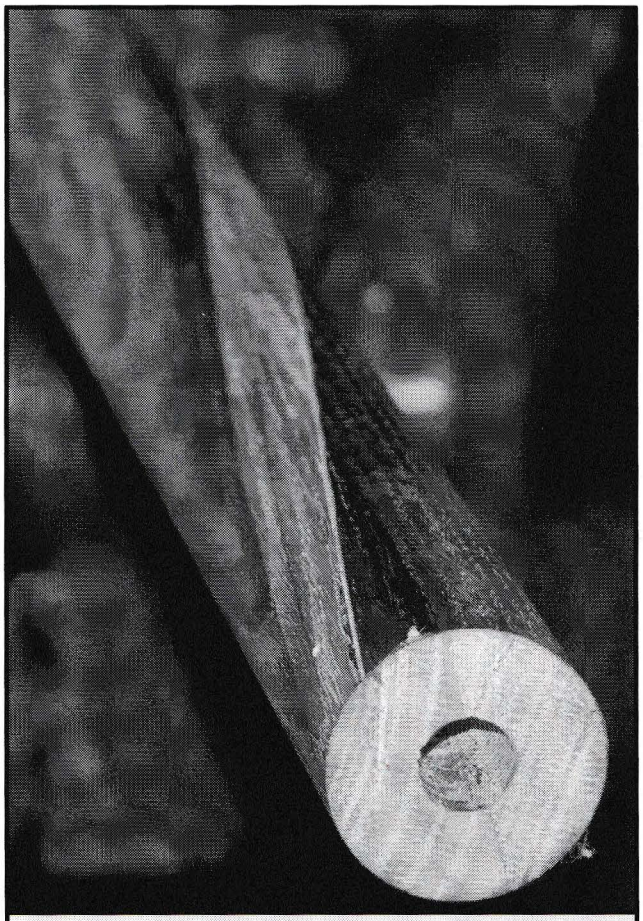
On the left is the center-drill guide bushing. On the right, an axle hole is being drilled.

The center-drill is used only to mark the exact center and start the hole in the proper location so that the twist drill won't wander as it enters the workpiece. The rifling cylinder is centered in the spindle of the barrel machine as if it was a barrel blank. Then a purpose-built ½" twist drill adapter is inserted into the universal block's tooling adapter and one end of the cylinder is drilled to a full depth of 2½". The rifling cylinder is then swapped end-for-end in the machine and the second hole is drilled. There is no need to engage the half-nut and feed the drill with the leadscrew. The hand-crank provides sufficient control for cutting wood with a manual feed. Of course, a lathe can also be used for drilling the axle holes if the lathe's bore is large enough to accept the rifling cylinders. Mine is not. My lathe's bore is 1⅛" ID and my rifling cylinders are 1½" OD, so I use my rifle barrel machine instead.

Before you start whittling away at the cylinder to cut the indexing groove, it is very important to make absolutely certain that the helix is properly laid out. The procedure of wrapping the cylinder with the steel tape and marking the helix with spray paint establishes the correct rate of twist, but now it's time to make sure that the line around the cylinder is perfectly straight. The best way to make sure that the cut-line is started straight is to mark it with stock checkering tools. I use a short section of the steel tape as a flexible straight edge and lay it along the spray painted line to lightly scribe the wood. The slight indentation formed by the scribe is used as a guide for a checkering tool to get the line started. One pass with a fine checkering cutter is all that is needed to establish the line. I then use a jointer (Monty Kennedy's design) to deepen the line slightly while straightening the slight waviness that invariably occurs when cutting across the grain in wood as tough as oak. Once a nice, straight V-groove is cut the full length of the cylinder, I use a compass to draw in the guide line for the other side of the groove. The distance between the compass point and the point of the pencil it holds is set to slightly less than the final, full width of the groove. The point of the compass is then dragged lightly along in the groove cut with the checkering tool while the pencil draws the line marking the other side of the finished indexing groove. Only one side of the

groove will actually contact the shoe to index the rifling twist during the cutting stroke, so only one side of the groove will need to be started with the checkering tools to ensure perfect straightness. The compass-drawn line is sufficiently straight for the off-side of the groove.

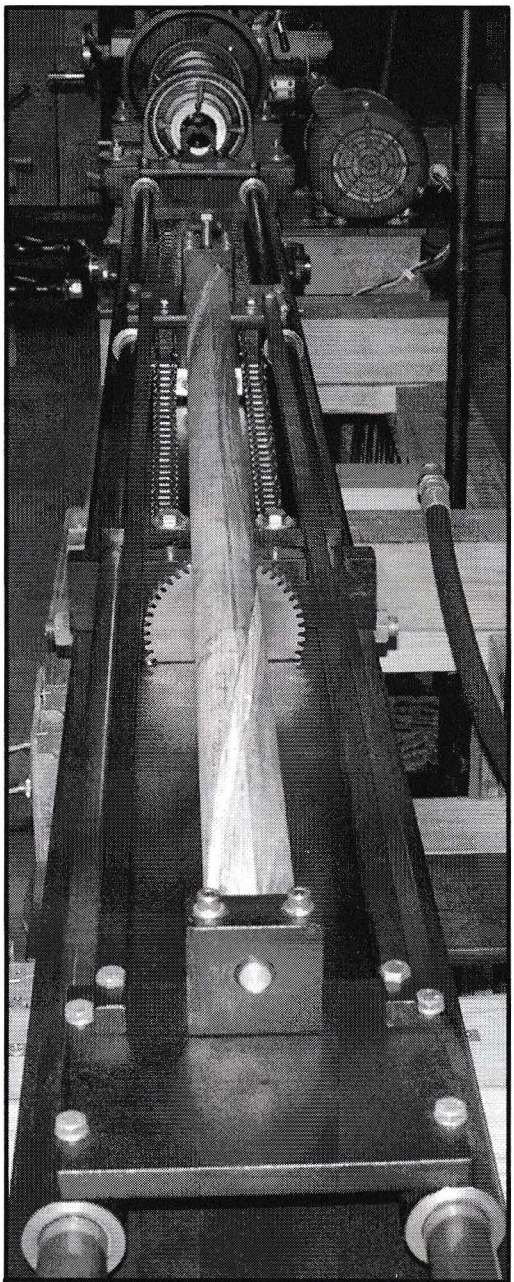
To cut the groove accurately, the best technique to use is the same one used for inletting the lock plate of a muzzleloader into the stock. First, use a chisel held in the vertical position to cut straight down into the wood fibers along both the checkering tool-cut line and the compass-drawn line. I use a ¼" chisel for the entire groove-cutting operation because larger chisels require too much force to cut through tough, stringy wood like oak. Be sure that the flat side of the chisel is pointing out so that the groove won't be unintentionally widened. The chisel is then held at an angle and pushed from inside the lines towards the outside until it cuts through to the vertical cut. This procedure lifts out a small strip of wood that is triangular in cross-section. This ensures that chiseling out the center will not tear out the grain along the edge and remove more wood than desired. After the corner cuts are made along both lines, the chisel is used to cut out the center of the groove to the depth of the corner cuts. Note carefully that the chisel is cutting under hand power only so far. Do not try to use a hammer to drive the chisel just yet or you will surely lift out more wood than you want to by cutting deeper than the cross-grain has been cut on the sides. In other words, you will ruin your rifling cylinder. I make one more pass under hand pressure alone to bring the depth of the cut to about ⅛" deep. Oak is very hard to cut under hand pressure alone and it will quickly cause your wrists and fingers to ache if the cut is continued in this fashion. So at this point, I do start using a small hammer to drive the chisel in vertically along the edges of the groove. However the cuts made at an angle, both towards the sides and along the length of the groove, are made under hand pressure alone to the full depth of the cut. It would be far too easy to drive the chisel in too deeply with a hammer when making these cuts. The groove needs to be cut to about ⅜" in depth. This is sufficiently deep for the shoe to get a good purchase on the side of the groove and positively drive the



The helix line is straightened with checkering tools. Note that the spray paint followed the grain to a certain extent; this is why the line must be checked for straightness. Also note the pencil line to the left representing the off-side of the groove.

twist of the rifling cutter box. This depth also spreads the forces involved over enough area to prevent torque-induced wear and damage to the rifling cylinder's wood grain.

When the groove is cut to full depth, I use a small, steel sanding block wrapped in 300 grit sandpaper to smooth the fibers along the sides of the groove. When done slowly and carefully, this sanding can also be used to remove any *minor* imperfections in the straightness of the groove's sides. I'm not referring to the straightness of the helix itself. If you've screwed that up, it's not likely that you will be able to fix it by sanding. What I'm talking about is the *vertical* straightness of the groove. I have found that the natural tendency (or, at least, my natural tendency) is to cut towards the center of the rifling cylinder. This will produce groove sides that are angled in relation to each other making the groove become narrower towards the bottom. The proper cutting angle is parallel to the line representing the radius at the *center* of the groove. If the groove was straight, this would be a piece of cake because all you would have to do is hold the chisel vertical when cutting down. However, because the groove spirals around the cylinder, the correct angle to keep the sides of the groove straight is constantly changing (when the cylinder is stationary in the vise) and the angle of the chisel must constantly change along the length of the cut. Proceeding slowly and constantly eyeballing the groove from the level of the cylinder's surface will go a long way towards preventing a narrowing of the groove as the cut deepens. But if the sides of the groove come out slightly angled in relation to each other, this deficiency can be corrected with the sanding block. Just make sure that the sandpaper doesn't touch the top portion of the grooves until the sides have been brought into agreement with each other. Then the full depth of the groove can be lightly sanded to the desired smoothness without producing any unwanted waviness in the groove.



The finished rifling cylinder is installed on the machine to check for smoothness of operation.

The axles of the rifling cylinder are made out of ½" round bar turned lightly in the lathe (if necessary to achieve a sliding fit) to fit ½" bearings mounted on each carriage. The axle that carries the back end of the rifling cylinder on the rear carriage only needs to be long enough to reach all the way through the bearing on that end. The front axle, however, must be

able to reach through the bearing and the universal block with sufficient length remaining to allow the rifling cutter box's pull-rod to be firmly attached. After the axles are cut to the proper length, they are epoxied into the rifling cylinder. Ideally, the axles should fit the drilled holes in the cylinder tightly enough that they have to be tapped into place with a rubber mallet. A snug fit like this helps ensure that they won't be able to rotate. It is a very good idea to also install a cross-pin through the rifling cylinder and front axle to ensure that the axle can never be broken loose. If this axle were to shift and spin during the course of a rifling operation, it is very unlikely that the rifling cutter could ever be realigned exactly with the half-finished grooves. Sure, the rifling cylinder's axle could easily be rehabilitated, but you will have to scrap the barrel you were cutting so it's best to play it safe and install a cross-pin.

Once the axles are in place, the rifling cylinder can be installed on the machine and run back and forth to make sure that the shoe does not bind in the groove at any point along the length of the cylinder. If it does bind, use the sanding block to open up the groove at that point by sanding the *off-side* of the groove. Do not sand the indexing side. It needs to remain nice and straight. It is also very important to make sure that the top of the shoe is not rubbing the bottom of the groove at any point. I allowed this condition to occur once when rifling a barrel and the extra friction on the cylinder caused it to lag a bit at the points of contact and this produced slightly wavy rifling. The defect in the rifling wasn't serious. In fact, no one else who looked through the barrel could even see what I was talking about. Still, that's not what rifling should look like, at least not to my eye. Fortunately, since the shank of the shoe is threaded, this situation is easily remedied by screwing the shoe down half a turn. Just make sure that you check for this condition and set the shoe at the same height for every barrel cut with that cylinder.

The final step in the fabrication of the rifling cylinder is to drill and tap the forward axle to accept a set-screw for the rifling cutter box's pull-rod. The pull-rods I use are made of 4130 tubing. For some calibers, a tube with an inside diameter of ½" is appropriate. For these calibers, the pull-rod can be slipped directly over the cylinder axle. For calibers requiring a tube of larger or smaller inside diameter, a short bushing can be attached to the pull-rod: inside bushings for larger-diameter tubes and outside bushings for smaller-diameter tubes. No matter what the configuration of the rear portion of the pull-rod, I drill a hole through its top that is just large enough to allow a 10-32 screw to pass through it. To locate the drilled and tapped hole through the cylinder axle, the cylinder is installed on the machine and the carriages are run all the way to the end of their travel (as far from the barrel spindle as possible). The rifling cutter box's pull-rod is then slid onto the axle and rotated until the hook cutter slot in the cutter box is pointing up. During use, this position will place the hook cutter in a convenient position for sharpening at the end of the cutting stroke. The cylinder axle is scribed around the perimeter of the hole through the pull-rod. After removing the cylinder from the machine, the axle is punch marked in the center of the scribed circle, then drilled and tapped to accept a 10-32 set-screw. I drill and tap all the way through the axle. This allows me to use a long set-screw that will go completely through the axle and then draw up tight against the opposite side of the pull-rod. This provides a very rigid mounting arrangement for the rifling cutter box.

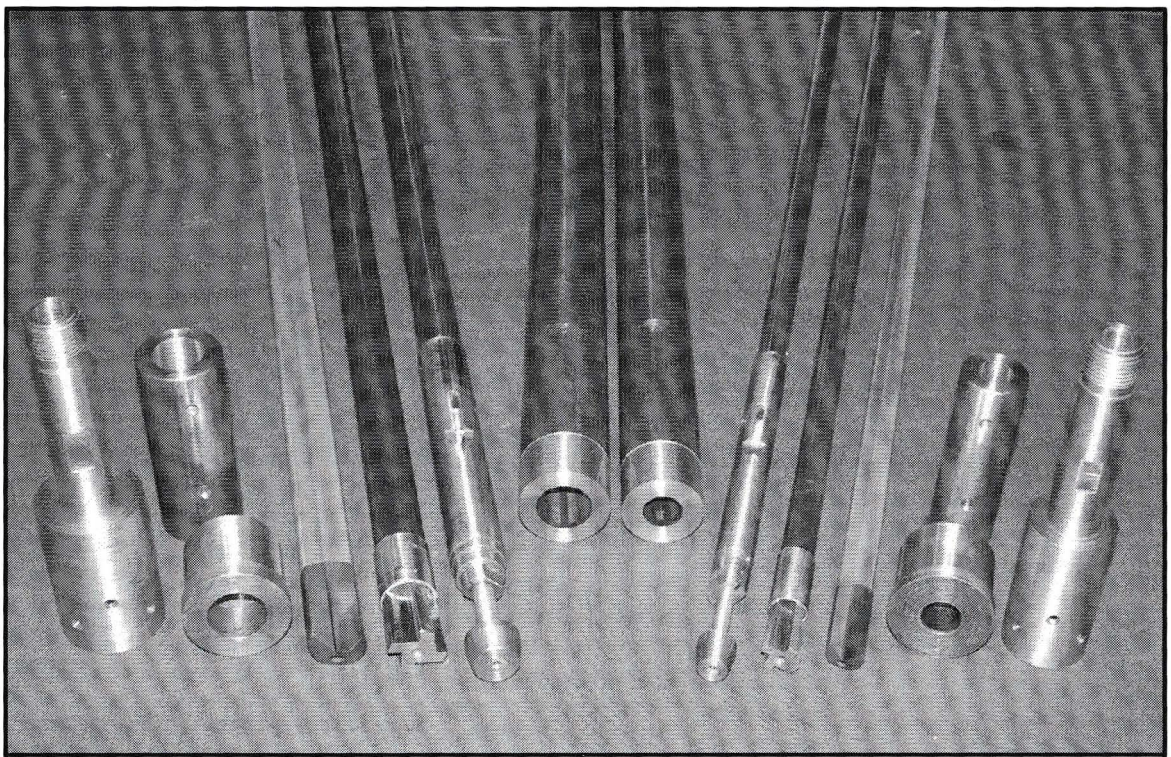
The literally finishing touch for the rifling cylinder is to put a few coats of wood finish on it. I use a teak oil finish that is formulated to be used on boat decks. While I

seriously doubt that I will ever have cause to take my rifling cylinders outside during inclement weather, I do want to protect them from seasonally humid air so that they will last a very long time. A finish that's designed to protect wood in a marine environment more than meets the demands of protecting my rifling cylinders from muggy summer air. To keep the cylinder running smoothly on the machine, I also use a paste wax designed for hardwood floors in the groove. The wax is smeared into the groove and then rubbed vigorously with a soft cloth to create a thin, slick wax topcoat. This stuff dries very hard and reduces the friction between the indexing shoe and the wood to a considerable extent.

I hope the preceding discussion has been sufficient to impress upon you the importance of getting the tools right before even thinking about actually trying to make a barrel. It takes a lot of time, patience and attention to details to get the tools right. But my statement at the beginning of this chapter was the absolute truth. Making rifle barrels really *is* all about the tooling, so make sure that you do take the time and pay attention to the details. If you persevere to this point, you will be the proud owner of a hand-built machine and hand-crafted tools which, together, are capable of making excellent rifle barrels. And as you proceed forward from this point, you will also find that the task of actually making the barrels isn't nearly as difficult as making the machine and tools. So now it's time to take a deep breath, relax and get ready for the project you *really* had in mind when you began this odyssey. It's time to make your first rifle barrel.

CHAPTER 7: Machining Operations

As with all machining operations, workpiece preparation and an accurate setup are required when machining a rifle barrel. Workpiece preparation is the prerequisite insofar as it sets the stage for making an accurate setup. If the surfaces of the workpiece are not true, then establishing a proper setup that precisely locates the work in relation to the cutting tools will not be possible. A barrel blank with smooth, consistent surfaces and accurate angles can be mounted on the machine in perfect alignment with the machine itself and with the cutting tools. The barrel blank should be thought of as a temporary component of the machine, with its positioning and alignment being just as important as the positioning and alignment of every permanent component. The two major aspects of the barrel blank setup are centering in the spindle and squarely interfacing with the drill guide bushing to form an oil-tight seal. If these two requirements are met, the drilling operation will proceed flawlessly and the finished hole will be perfectly straight.



Tools of the trade: 8-bore tooling on the left, 58 caliber tooling on the right. In the center lie two completed barrel blanks, one in each caliber.

With the barrel blank accurately mounted in the machine, there are three other factors that will determine the outcome of the drilling and reaming operations. These factors are speed, feed and oil flow (chip removal). If the speed of barrel blank rotation and tool feed are correct, the cutting tools will do their job efficiently and leave behind a very good surface finish when their work is through. Likewise, if the oil flow is set correctly for the rate of chip production generated with a particular combination of speed and feed, then the tools will cut true without binding. However, if one or more of these parameters is not as it should be, then the hole is not likely to come out very straight or smooth. A crooked, rough hole would suffice if the finished product was going to be used

as a sewer pipe, but this condition simply won't do when the objective is to produce an accurate rifle barrel.

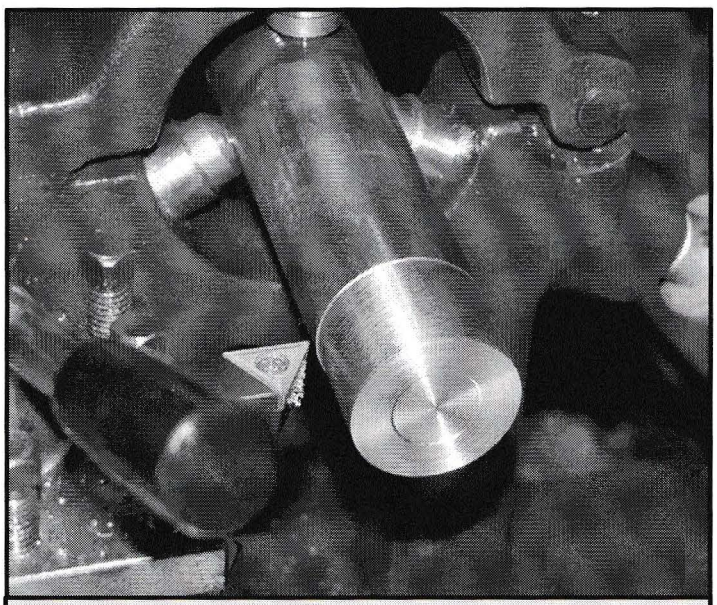
Of all the operations required to craft a rifle barrel from solid stock, cutting the rifling is undoubtedly the most challenging. Drilling and reaming, while important, are relatively easily accomplished when the parameters of the operation are balanced correctly. Rifling a barrel by the cut-rifling method, on the other hand, requires concentration and attention to detail. It also requires the barrel maker to be able to determine how the operation is proceeding based solely upon the feel of each successive cut. This is in stark contrast to drilling and reaming. With those operations, once the machine is set up and running, the barrel maker becomes little more than an interested spectator to an event that really isn't all that interesting. But the cut-rifling operation demands the barrel maker's complete and undivided attention. He must keep track of several different variables constantly and simultaneously. And again, this must all be done by feel because the cutting operation is entirely hidden from view. This is why most people who know anything at all about the subject have reckoned the cutting of rifling grooves an art, not a science. After learning this time-honored practice myself, I have to agree. Cut-rifling really is a cut above more common machining practices because it does indeed demand more from the machinist. While there are very real, very practical advantages to cut-rifled barrels, it is the finesse and care that go into making them that causes riflesmiths and shooters alike to hold them in such high esteem. Then again, all of that finesse and care also tend to make cut-rifled barrels very good performers on the range and in the field, so maybe that's why they're held in such high esteem. Regardless, this chapter deals with the nuts and bolts of actually making those coveted, cut-rifled barrels.

Setup

The barrel blank needs to be cut a little bit longer than the desired finished barrel length. Because of the lack of support for the reamer and rifling cutter box at each end of the barrel blank, these tools will cut differently at the ends of the barrel blank than they do in the middle. As the reamer leaves the barrel, it has absolutely no support from the guide bushing. Additionally, the cutting oil has to be turned off an instant before the bushing clears the blank to prevent spraying cutting oil all over the shop. The combination of these factors causes the reamer to cut a far rougher surface finish over the last inch of barrel length than it does through the remainder of the barrel. As for the rifling cutter box, it tends to cut a bit shallower as it enters and leaves the bore because the cutter is not supported by the full length of the cutter box when this condition occurs. The end result is that the bore quality suffers at each end of the barrel and conventional wisdom says that these less-than-perfect sections must be cut off. Now in the case of muzzleloader barrels like the ones I make, one end of the barrel will be bored out and threaded for the breech plug anyway, so only one end of the barrel (the muzzle) will need to be cut off later. However, there is one more reason to make the barrel blanks a bit longer than the finished length. If the barrel will have a tapered profile turned on the lathe, a lathe dog will have to be installed on one end during the operation and the length of barrel occupied by the lathe dog can't be turned. So, to allow an inch to be cut from the muzzle end and a couple more inches to be cut from the breech end where the lathe dog sits during profiling, I make my barrel blanks 3½" longer than the desired finished

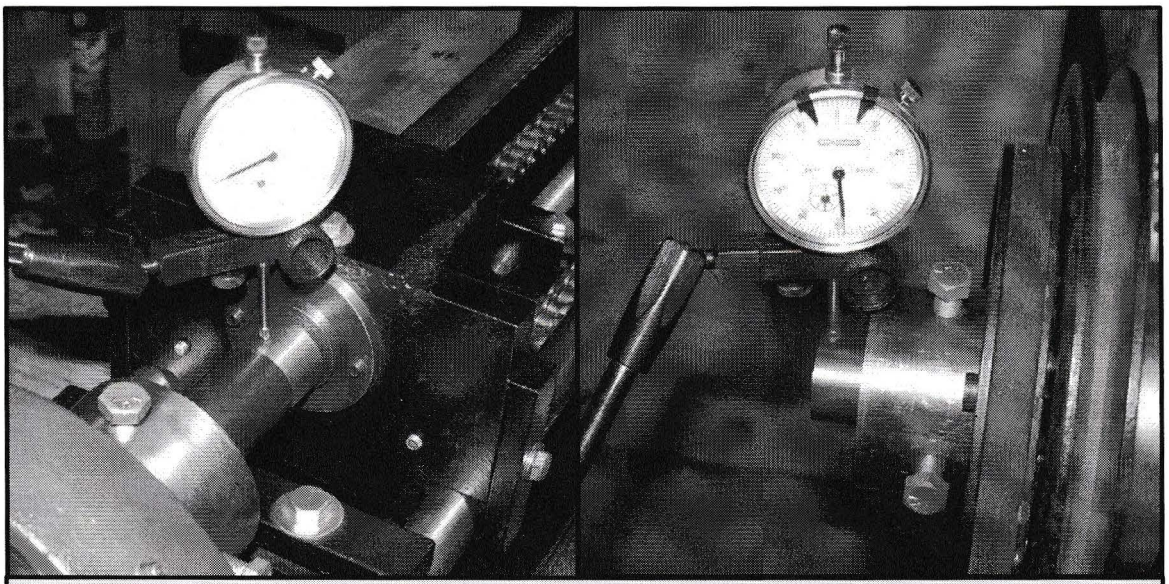
length. Incidentally, even if you're making a full-octagon muzzleloader barrel and the final profile will be cut in a mill instead of a lathe, it is still beneficial to turn the exterior surface of the blank concentric with the bore in the lathe before milling. This will make the barrel easier to center in the milling fixture. So, no matter the finished profile of the barrel, plan to turn the profile in the lathe with the use of a lathe dog.

Before installing the barrel blank in the spindle of the rifle barrel machine after it's cut to length, it needs a little bit of prep work. My barrel blanks are too large in diameter to fit through the spindle of my lathe, so the prep work is accomplished with one end of the barrel blank centered in a four-jaw chuck and the other end centered in the steady rest. Journals are turned around the circumference of the blank on each end. Only a few thousandths of an inch of material need to be removed to ensure that the surface is uniformly smooth and round. This surface will be used to indicate the blank to center in the barrel machine spindle. In addition, one end of the barrel blank needs to be machined perfectly square. This is the surface that will tightly interface with the drill guide bushing to prevent cutting oil from seeping out. This was the extent of the preparation for the first few barrels that I made. However, I have found that going one step further pays big dividends. Those first couple of barrel blanks allowed quite a bit of oil to leak out onto the machine during the drilling operation. I traced the cause to a very slight burr that the deep-hole drill raises around the periphery of the drilled hole. The burr was being forced away from the drill with sufficient force to drive the bushing plate/chip box assembly a few thousandths of an inch away from the face of the barrel blank, thus causing the leak. Since discovering this, I have made a habit of cutting a very slight counter-bore on the face of the barrel blank. This counter-bore is cut .015" deep and .020" larger in diameter than the deep-hole drill. This keeps the burr away from the drill guide bushing and the oil leaks have stopped.



This barrel blank has been prepped. Note the slight undercut on the face to allow room for the burr pushed up by the drill.

The first step in setting up the barrel machine is to remove the cat-head bolts from the outboard end of the barrel spindle. This allows the pulleys to be rearranged for drilling speed (if you're like me, you will leave the reamer pulley in position until it is time to drill again). After the drilling pulley is put into position, the cat-head bolts can be replaced. The drive belts are left off for now so that the spindle will be easier to rotate while centering the barrel blank. Put the bushing plate/chip box assembly, with drill guide bushing installed, in position. Don't tighten down the strap clamps yet. At this point, it is just sitting there to gauge how far through the spindle to slide the barrel blank.

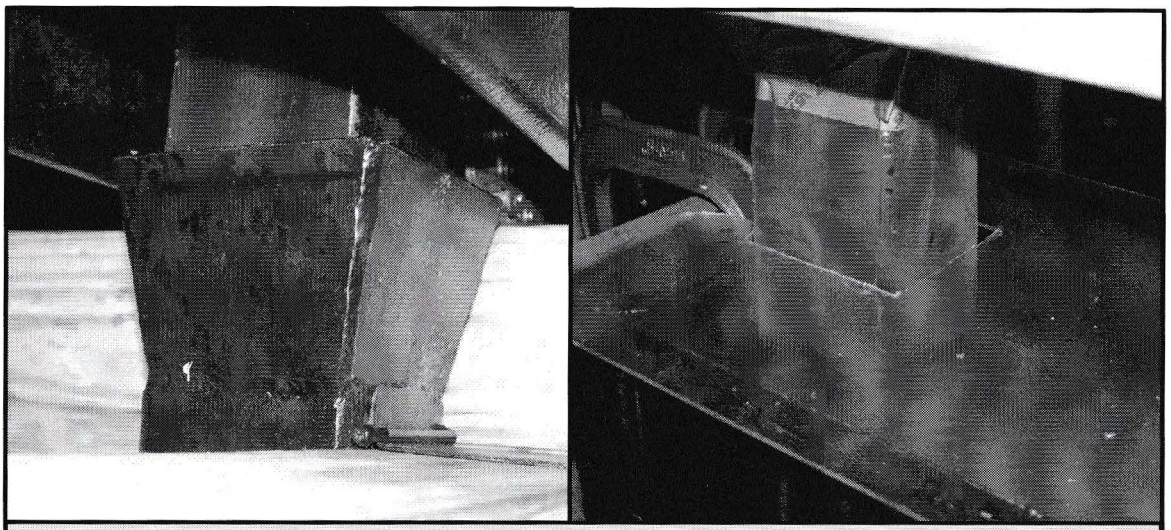


This is the procedure for centering the barrel blank in the spindle, fore and aft.

The barrel blank can then be inserted into the spindle and its face brought into contact with the drill guide bushing. Centering is accomplished by the use of a dial indicator on each end of the blank. The cat-head bolts are adjusted by the same procedure as a four-jaw chuck until both ends run true. When the barrel blank is running true and the cat-head bolts are snugged down tight, the bushing plate/chip box assembly is pulled forward to bring the drill guide bushing into firm, square contact with the face of the barrel blank. Tighten the strap clamps until they are just snug, and then bump the back of the chip box with a rubber mallet to firmly seat the bushing against the barrel blank. Then carefully tighten the strap clamps with sufficient force to ensure that they can't vibrate loose. This is also a very good time to put the funnel into position under the chip box. Forgetting to install that little bugger would amount to a pretty messy and costly mistake. Once the barrel blank setup is complete, the spindle drive train can be set up. If necessary, the idler pulley is swapped out for one of a different size to achieve the appropriate cutting speed. Then the drive belts are put into position and the idler pulley is tightened down.

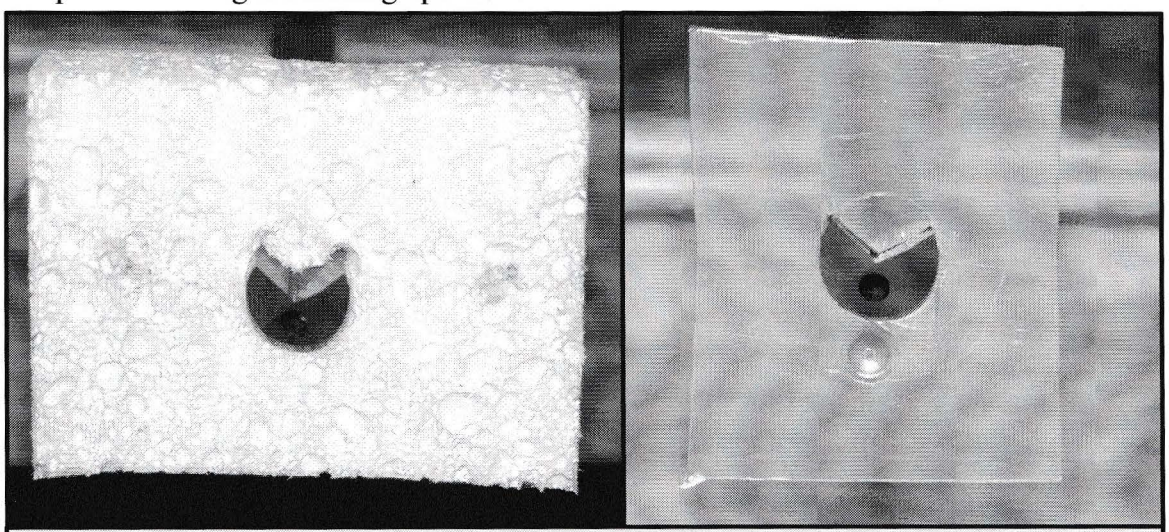
Deep-Hole Drilling

It is impossible to appreciate the quantity of chips produced when drilling a rifle barrel until you have actually seen a deep-hole drill in action. To ensure that this copious quantity of chips is efficiently removed from the cutting oil before they can get into the hydraulic pump, the chip collection basin needs to be thoroughly prepped before drilling. The screens in the bottom of the chip collection basin need to be cleaned and a new filter placed between them. It is also a good idea to inspect the grid of magnets under the basin. The magnets are capable of catching the errant chips from up to two barrels without adversely affecting oil flow back into the reservoir. After the second barrel, the magnets will have grown fuzzy enough to restrict the gravitational flow of oil to such an extent that I feel it is necessary to scrape the chips off before drilling a third. The design of my oil catchment system includes a removable trough for collecting the oil during the reaming operation. There is a square hole in the wall of the chip collection basin for this trough that must be sealed off during the drilling operation. I made a simple metal plate



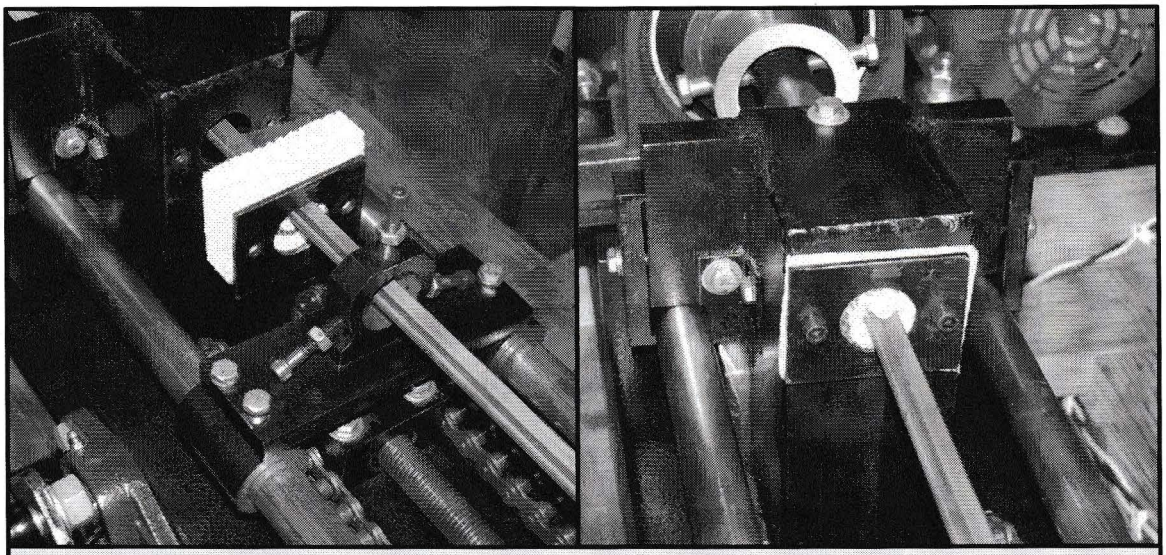
On the left is the funnel that sits below the chip box chute. On the right is the plastic skirt at the bottom of the funnel and the Plexiglas cover over the area of greatest oil splashing. The Plexiglas allows me to see when the pile of chips is getting high enough that it needs to be cleared away.

with rubber gasket material around its perimeter for this purpose. The plate is placed over the hole and a pair of C-clamps are used to hold it in place. After drilling a couple barrels, I also recognized the need for some extra splash protection. To this end, I taped a plastic skirt around the bottom of the oil funnel. This skirt passes through a Plexiglas splash guard that sits on top of the chip collection basin to prevent precious drops of cutting oil from being lost onto the shop floor. Plexiglas was used so I can keep an eye on the area directly under the chip box. This area accumulates chips rapidly and must be periodically swept clean during the drilling operation.



Here are the sponge gasket and the plastic facer that is designed to protect it from chips.

Before installing the drill on the machine and letting the chips fall where they may, a gasket needs to be made to seal the back of the chip box around the deep-hole drill. As discussed in a previous chapter, the gasket is made from a regular household sponge with a plastic facer in front of it to prevent the chips from tearing up the sponge. I



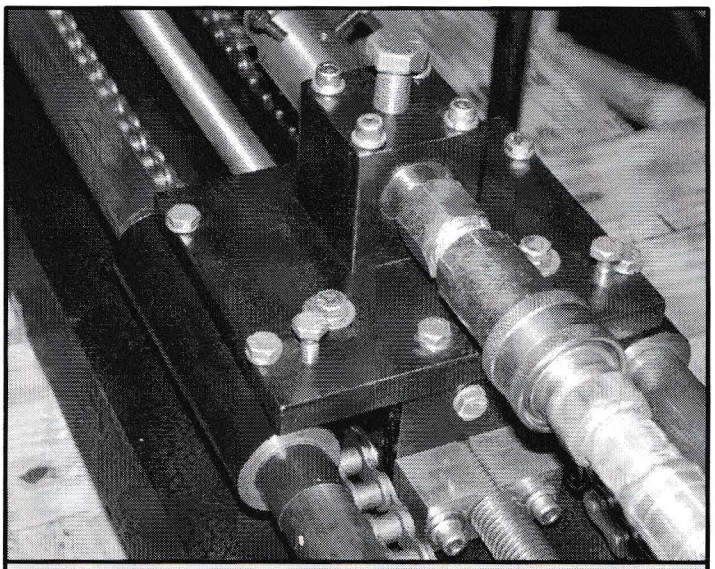
On the left, the gasket backing plate, gasket and plastic facer are slid onto the deep-hole drill shank. On the right, the entire gasket assembly snugged down tight with the backing plate screws.

do not cut out any material from the sponge when making the gasket. I simply cut a shallow V in the appropriate location so that the sponge will be nice and tight around the shank of the drill. Once the gasket is made, the tooling adapter is installed in the universal block of the forward carriage and the set-screw is tightened to hold it in place. The drill is first poked through the steady rest and then the gasket backing plate, gasket and plastic facer are slid onto the shank of the drill. With the carriage at the rearmost point of its travel, the drill is installed. Insert the drill into the chip box and on into the drill guide bushing first, then slide the carriage forward to insert the drill driver into the tooling adapter. With the drill supported by the drill guide bushing and the driver supported by the universal block, insert the screws through the gasket backing plate, gasket and plastic facer. The whole conglomeration can now be slid forward on the drill shank and secured in position on the back of the chip box with the screws. Before locking the half-nut into position on the leadscrew, I like to slide the carriage back about $^{1}/_{16}$" to make sure that the drill is not in contact with the barrel blank when the machine starts. I don't know if this is necessary, but I just don't like firing up the barrel spindle while the drill is making contact with the workpiece.

The tooling adapter is locked into the universal block and the drill driver is locked into the adapter.

Now the half-nut can be

locked onto the leadscrew by sliding the two halves into position and holding them in place while tightening the screws. The female hydraulic quick-disconnect is installed on the rear of the tooling adapter and tightened until just snug. Remember that there is an O-ring seal in the threaded end of the quick-disconnect and an excessive amount of torque can squash and tear the O-ring, so don't overdo it. The oil flow is set for the size of drill being used by installing a pulley of the proper diameter on the shaft of the hydraulic pump motor. Before inserting the hydraulic line's male quick-disconnect into the universal block's female quick-disconnect, I test the high-pressure oil system by running it for a few minutes to make sure that everything is working properly. Open the flow control valve all the way to avoid dead-heading the pump, then slowly close the flow control valve a bit at a time to take the system up to peak pressure for the size of drill being used. After checking to make sure things are as they should be and there are no leaks, the pump motor is turned off and the hydraulic line can be inserted into the rear of the tooling adapter assembly to begin the drilling operation. Turn the flow control valve back to the full-open position. Maximum pressure is not required when the drill is just starting into the workpiece.

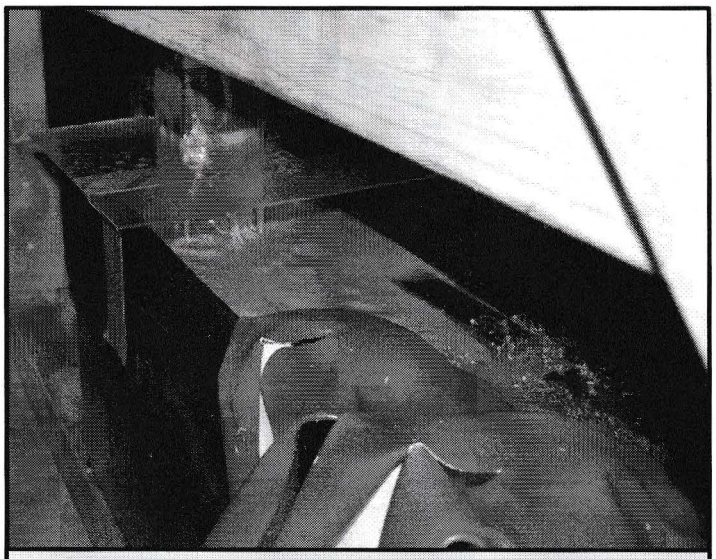


The half-nut is locked around the leadscrew and the hydraulic quick-disconnect is installed on the tooling adapter. Note the electrical tape on the near bed bar marking the start location of the carriage.

The progress of the drill through the workpiece will need to be monitored so that the machine can be shut off before the drill exits the other end of the barrel and blows oil all over the shop. The simplest way I have found to keep track of the drill's penetration is to wrap a strip of electrical tape around one of the bed bars at the rear of the carriage. As the carriage moves forward, a tape measure can be used to measure the depth of the hole by measuring the growing gap between the rear of the carriage and the electrical tape. If the idea of using tape wrapped around a bed bar doesn't appeal to your sensibilities, it would be a simple matter to make a sliding gizmo with a set-screw that would fit around the bed bar and could be slid up tight to the back of the carriage and locked into position. If you do this, it would be a good idea to use a brass set-screw so the bed bar isn't marred by the screw.

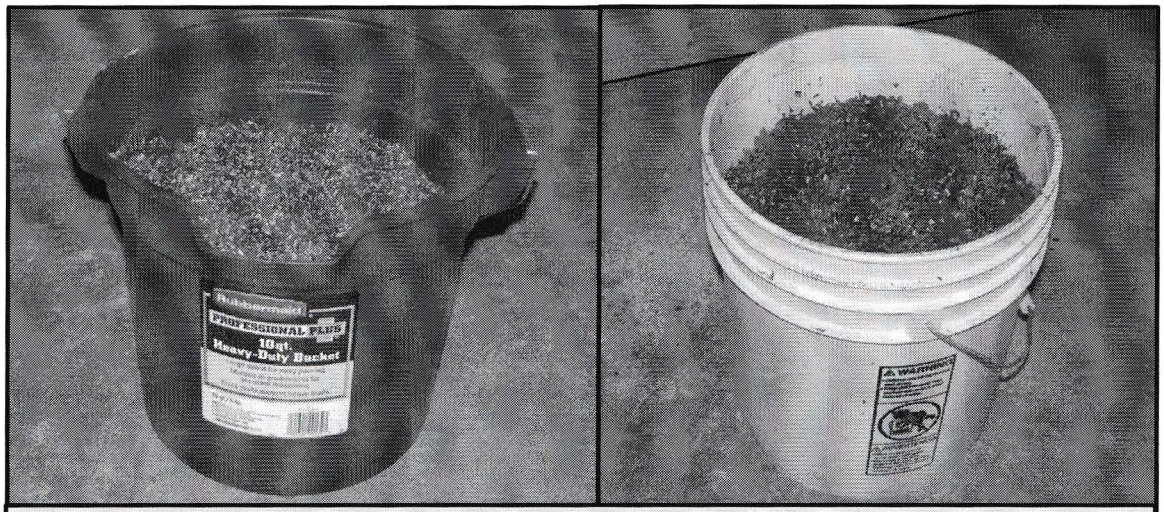
The machine is now ready to begin the drilling operation. All that remains is to switch everything on and monitor the drill's progress. I always use the same sequence to start the machine. First, I turn on the hydraulic pump motor and check to make sure that oil is flowing freely through the drill and dumping back into the reservoir as it should. I also set the flow control valve to bring the oil pressure up to 100 psi. This is all the pressure required to start the operation and the lower pressure helps keep oil from leaking

between the barrel blank and the drill guide bushing. Remember, at this point in the process, the oil is blowing straight into the flat face of the barrel blank and this makes leaks far more likely. Once the drill has progressed an inch or so down the barrel, the oil will be flowing backwards, thus directing the flow into the chip box instead of sideways towards the interface between barrel blank and bushing. When sufficient oil flow is confirmed, the barrel spindle is double-checked to make sure that the screw used to index the location of the rifling grooves has been completely removed from the machine. Turning on the spindle motor while the spindle is locked in position wouldn't be a very good idea. Once this final check is made, the barrel spindle is turned on. If the strap clamps on the bushing plate haven't been sufficiently tightened, the sudden movement of the barrel blank may cause the plate to tilt away from the barrel blank slightly. If this occurs, there will be a very noticeable oil leak. If oil is leaking out, shut down the machine and reset the bushing plate. When both the high-pressure oil system and barrel spindle are running smoothly, the leadscrew gearmotor can be turned on to get things under way. Make sure you check the position of the forward/reverse switch for the leadscrew motor to ensure that the screw will be rotating in the right direction before turning on the power at the speed control. There is no need to gradually ramp up the feed. The dial on the speed control is turned on and immediately cranked to the correct percentage setting for a full cut. I will not go into the speed and feed requirements for drilling again here since those parameters were already covered in the chapter dealing with the high-pressure oil system. After the proper feed rate is set, quickly check everything to make sure that the machine is operating the way it should and then start watching the oil flowing out of the chip box. When you start seeing those first few shiny silver chips collecting on the screen, you will know that all is well and the drilling operation has officially commenced.



This is what good oil flow looks like when drilling. Note the rubber gloves draped over the side of the chip collection basin.

Over the course of the drilling operation, the most pressing concern for the barrel maker is to keep the chips that are produced from clogging the filtering screens in the chip collection basin. It only takes a few minutes for quite a pile of them to build up at the point of discharge and the buildup quickly begins to restrict oil flow through the screens. To keep the screens clear, I use a round magnet with a handle to pick up the chips. The chips are then scraped off of the magnet and moved to the back of the chip collection basin where they can't interfere with oil flow. There, at the back of the basin, the chips sit contentedly while gravity slowly drains the cutting oil out of them and back into the reservoir. I use a pair of heavy-duty rubber gloves when clearing the chips from under the chip box for two reasons. First, and most obviously, I don't want to get cutting



What quantity of chips does a deep-hole drill produce? On the left– a 2½-gallon bucket full of chips from a 58 caliber barrel. On the right– a 5-gallon bucket full of chips from an 8-bore barrel. That's one barrel's worth of chips for the respective calibers in each bucket...

oil all over my hands. But even more importantly, the gloves keep the needle-fine chips from pricking into my hands. During the course of drilling my first barrel, I did not have any rubber gloves handy that were tough enough to stand up to the abrasion and cutting action of the chips, so I cleared them away with my bare hands. By the time the drilling operation was complete, I had literally hundreds of tiny steel slivers embedded in my fingers and palms. They hurt like the dickens and were impossible to dig out. If it weren't for the fact that our skin is constantly shedding, one cell at a time, those chips would still be in my hands. I had to wait for them to wear out as the skin cells beneath them divided and pushed fresh skin to the surface. Moral of the story: *never* touch the chips produced by a deep-hole drill without first donning some heavy-duty rubber gloves. Incidentally, I split my gloves up the back so that I can slide my hands in and out of them without actually grasping the gloves and pulling them on and off one at a time with the opposite hand. This quick-fit feature comes in very handy (no pun intended) when the gloves are dripping with oil. The gloves never leave the basin. They slide off my hands to drape over the side of the basin and stay there until needed again or until they have dripped dry. Cutting oil is very expensive and unbelievably slippery, so it's worthwhile to take precautions against dripping it all over the floor and slathering it all over your tools.

The other major concern during the drilling operation is maintaining oil pressure. When the drill has progressed about half an inch into the barrel blank, I begin turning up the pressure from 100 psi. The pressure is slowly increased every so often until the oil is running at the target pressure by the time the drill is two inches into the barrel blank. Once the flow control valve is adjusted, the oil will run smoothly for a while. However, the heat produced by the drilling operation will slowly heat the cutting oil. As the oil heats, its viscosity will drop and so will the pressure because lower viscosity makes the oil easier to pump. For this reason, it is a very good practice to check the oil pressure every couple of minutes and adjust the flow control valve as necessary to maintain the proper pressure. It is also good practice to inspect all of the various interfaces between components that have oil flowing through them to make sure that no leaks develop due to vibrational loosening. My machine has never sprung a leak during a machining operation,

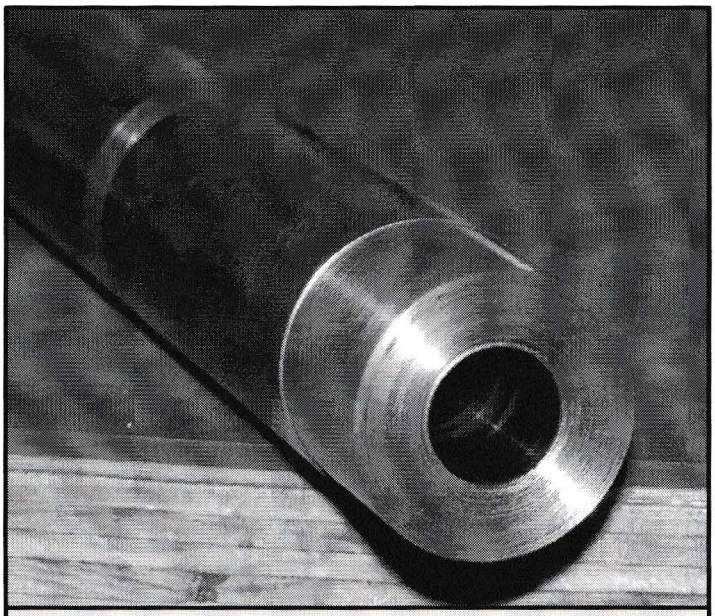
but I know that Murphy is quietly biding his time and waiting for me to stop paying attention, so I check for leaks often. Besides, there's nothing else to do except clear chips while the machine is drilling, so I might as well check something. To date, the only place my machine has ever leaked so much as a single drop is at the juncture between the barrel blank and drill guide bushing. When first starting the drill into the workpiece, it is common for an occasional drop of oil to leak here– about three or four drops a minute. I place a small piece of plastic under the barrel blank and direct these few stray drops into the oil funnel with it. Once the drill has progressed five or six inches down the bore, the dripping stops. I think that the barrel blank and bushing expand just enough to seal off the oil due to the heat being produced (the oil gets well over 100° F), but I'm not sure about that. It might simply be a case of the oil pressure dropping the further from the drill tip it gets. But either way, the dripping isn't severe and it doesn't last long.

Barring any unforeseen calamities, the only other thing for the barrel maker to watch out for during the drilling operation is chip packing around the drill. No, you can't see this take place, at least not directly. But if chips start to pack around the drill due to insufficient oil pressure, you will be able to see the drill shank start to intermittently twist ever so slightly in fast little pulses. This is a danger sign. If the condition is not corrected, the chip packing will become more severe and this will really bind the drill. When this happens, the drill shank will begin to twist and jerk alarmingly. This event will also be accompanied by a screeching squall that is caused by the dramatically increased friction between the drill and the barrel blank. If this happens, *stop the feed immediately* to avoid damaging the drill and allow the oil to flush all of the chips out of the barrel before doing anything else. There are two ways to correct this unhappy situation without decreasing the cutting speed. The best option is to increase the oil pressure so that the chips can be flushed out with enough vigor to keep things running smoothly. However, if the hydraulic pump is already pumping at the highest pressure it can produce, the only other option is to shut the machine down and wait for the oil to cool back to room temperature. Once the oil has cooled, its viscosity will be back to what it should be and the pump will be able to bring the pressure up to the recommended value. Make sure that you do wait until the oil has cooled all the way back to room temperature.

During the period when I was experimenting with cutting speeds to determine how quickly my machine could drill when pushed to maximum capacity, I tried drilling at a speed that my hydraulic pump and motor just couldn't keep pace with as the oil heated. The aforementioned twisting and squalling of the drill started as the oil got hot (how else would I know what it looks and sounds like?). Since I was trying to gauge maximum speed, I would only allow the oil to cool for a few minutes and then start up again. Needless to say, a few minutes later the twisting and squalling would begin anew, forcing me to shut down the operation once more. I drilled about six inches of the bore in this fashion before I decided that I'd seen enough and allowed the oil to cool back to room temperature. After the oil had cooled, the remainder of the drilling operation went smooth as silk. But when I inspected the finished hole, I found that the bore had a pronounced bow in the section that was drilled while the drill was chip-packed. If I remember correctly, it wandered some .006" off-center in the affected area. Beyond that point, in a stunning testament to the perfection of design employed in contemporary deep-hole drills, *the drill sought and found the exact center of the barrel blank again* within an inch of regaining sufficient oil pressure to clear the chips. Of course, that

particular barrel blank and its dog-legged bore were relegated to the scrap heap, but that was one experiment that definitely taught me several very valuable lessons. Not the least of which is the fact that deep-hole drills can and will do excellent work if I hold up my end of the deal. That kind of first-hand knowledge inspires a lot of confidence in one's tools.

If everything goes well, you will eventually end up with a bar of steel with a hole through it that is rapidly approaching finished depth. I usually stop the feed when the measurement between the carriage and the electrical tape is ¼" under the total length of the raw steel bar. By shutting down the machine at this point, I can rest assured that the drill is not going to poke through the far end of the barrel. After everything comes to a standstill, the hydraulic line is disconnected. Then the half-nut is disengaged and the carriage is run all the way back to the starting point with the rapid traverse hand-crank.



Note the burr kicked up around the edge of the hole in a freshly drilled blank and the tool marks in the bore; hard to see here, but they are one to two thousandths deep.

When removing the deep-hole drill, pause for a couple seconds with the tip of the drill still inside the chip box and raise the driver of the drill a bit. Oil remains in the drill shank after the pump is shut off and the best place to drain it out is inside the chip box. Since the top of my bench is completely open, I can stand the drill upright (driver down) in the chip collection basin right through the top of the bench to allow the rest of the oil to drain out. When removing the barrel blank from the spindle, I turn the cat-head bolts on the inboard end of the barrel just enough to loosen them. Then I loosen the bolts on the outboard end and retract them from the spindle far enough to tilt the barrel down. This causes the residual oil in the barrel to flow towards the head of the hole instead of spilling out all over everything. Once the barrel is clear of the spindle, it can be placed in the chip collection basin, open end down, alongside the deep-hole drill to drain. Before proceeding with the reaming operation, the closed head of the bore has to be sawn off. This task can be done with a band-saw or a hacksaw, it really doesn't matter which. The blank is then placed in the lathe to face the cut end smooth before returning it to the barrel machine for reaming.

You may be wondering why the sawn end of the blank needs to be faced if it's just going to be cut off again after rifling in order to remove the less-than-perfect rifling at the very end of the bore. I once wondered the very same thing. It turns out that the reason for this step is to ensure that the rifling cutter box's hook cutter has a perfectly square surface on which to begin the cut. If the end of the barrel is left in the rough-hewn condition, the hook cutter is encouraged to skip and fail to cut as it enters the bore only to

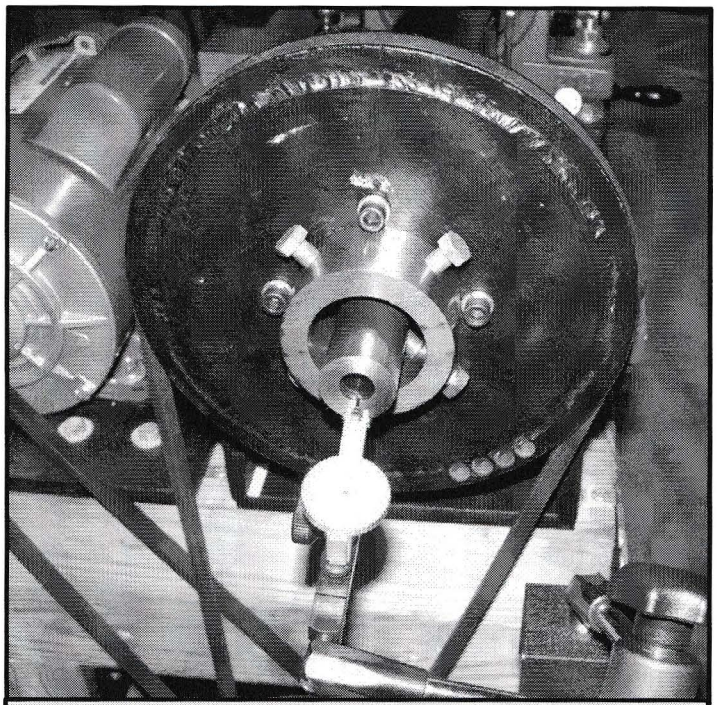
gouge in abruptly a bit further down the line. Don't ask me why 'cause I don't know– it just does. And in case you're the curious type who's now wondering if I learned that precious little nugget of truth the hard way; yes, unfortunately, I did. Even more unfortunately, the barrel can't be removed from the spindle once rifling has begun unless it's being removed permanently, as in the rifling operation is complete. Have you ever seen some poor, misguided knucklehead trying to file the vertical face of a horizontal, waist-high bar of steel perfectly smooth and square while muttering a more or less constant stream of profanity? Witnesses report that the spectacle is quite entertaining, although my own personal opinion is that the "must-see" character of the event has been greatly exaggerated. However, I take great pleasure in reporting that the rather unconventional metal-working operation was (eventually) a smashing success that resulted in a tack-driving barrel, once the grooves were evened out and the cut became uniform from end to end.

Reaming

Reaming is the one and only machining operation that is conducted in the course of making a rifle barrel that allows the barrel maker to relax a bit. Drilling demands constant attention to the operating parameters of the machine and, if something goes wrong, you could potentially ruin a barrel *and* a very expensive drill. Rifling requires complete concentration and attention to detail and also carries the make-it-or-break-it mystique that weighs heavily on the barrel maker's mind as he toils away hour after hour. Reaming, on the other hand, is fast and care-free. The operation proceeds at twice the speed of drilling, the hydraulic pump has no trouble whatsoever in getting enough oil to the cutting edges, and the flour-like consistency of the chips produced can't possibly cause a well-lubricated reamer to bind. In other words, there is very little that can go wrong with a reaming operation. And the pay-off at the end of it all is nothing short of breathtaking. The first time the barrel maker looks through a freshly reamed bore and sees that smooth, sparkling finish, he is very glad indeed that he decided to get out of bed that morning.

After cutting off the solid end of the bar to reveal the drilled bore in all its glory and facing the barrel in the lathe, the barrel blank is ready to be reamed. But before returning it to the barrel machine spindle, the outboard cat-head bolts are removed from the spindle once again to change pulleys and set the speed for reaming. Once this task is complete, the barrel can be indicated to center in the spindle as before, with one minor change in the procedure. When centering the blank for the drilling operation, the barrel blank was indicated on the journaled surfaces turned on the outside of each end. That procedure remains the same for the end of the blank that the drill entered because the drill entered absolutely dead-center in the blank. However, the end that was cut off is indicated to center on the *inside* surface of the freshly drilled bore. The reason for this is that the deep-hole drill will undoubtedly have run off-center a bit. It won't be off by much, just a few thousandths, but it will be off. By indicating the bore instead of the outer surface, you can be sure that the bore, which is the only surface of the workpiece that matters at this point, is running true to the centerline of the spindle. If so desired, an indicator can also be placed on the outer journal surface to measure the amount of run-out that occurred during the course of the drilling operation. Simply determine the total indicator reading and divide by two and the resulting figure is the amount, measured in

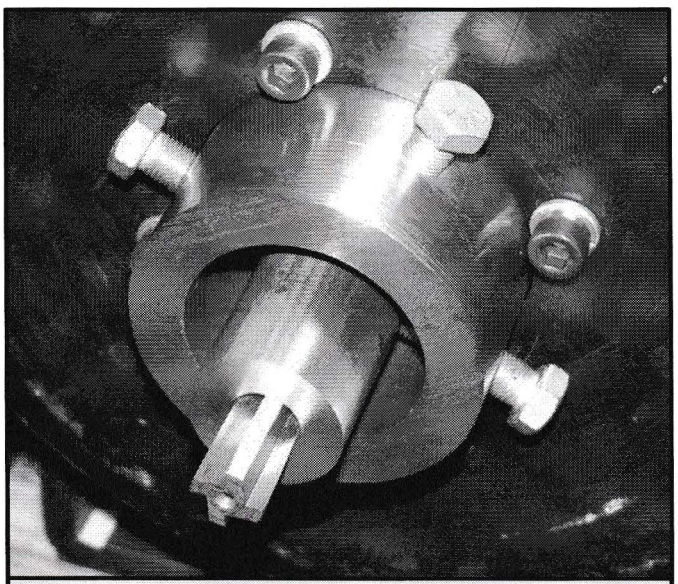
thousandths of an inch, by which the centerline of the bore is in disagreement with the original centerline of the barrel blank. If the bore is off-center by more than .015", you may want to discard that barrel and start over if maximum accuracy potential is a concern. But if your machine is built and operated correctly, you will likely never have to discard a barrel due to bore run-out. The worst bore I've ever drilled (except the dog-legged one I mentioned earlier) was .007" off-center at 31" from the point where the drill entered the blank. This amount of run-out won't affect the accuracy of the finished barrel in the least if the run-out is gradual (no dog-legs), because the later profiling operation will cut the finished surface of the barrel concentric with the bore. Once the barrel blank is centered and secure in the spindle and the run-out measurement has been verified to be within acceptable tolerances, the spindle drive belts are installed with an appropriately sized idler pulley for the speed at which you want to ream.



The ID of the barrel blank is indicated to check for run-out and center the barrel blank for reaming.

It is recommended that the speed for reaming be kept at ½ to ⅔ the speed used to drill the same material. In the case of most steel alloys used for rifle barrels, the maximum drilling speed will be around 120 to 130 fpm. For these materials, the proper speed to run a reamer would be anywhere between 60 and 87 fpm. Since the deep-hole drill is made of carbide and most commercially-made reamers are made from high-speed steel, you would be well advised to choose the lower speed setting. I only make large-bore muzzleloader barrels and I use 1144 steel for my barrel blanks because tougher, more tenacious alloys simply aren't required to contain muzzleloader pressures. The speed for drilling this steel is 190 fpm, which means that a high-speed steel reamer could be run at 95 to 127 fpm. However, when using tools made from carbon steel, such as O-1, the recommendation is to run at ½ the speed used for high-speed steel cutting tools. In order to obtain maximum life from my reamers, it is best to use a cutting speed just under 50 fpm for reaming. If you use reamers made from a tougher grade of steel, you will be able to increase the speed of the reaming operation significantly. Just make sure that you don't exceed the limits of the material that the reamer is made of or your reamer won't last long.

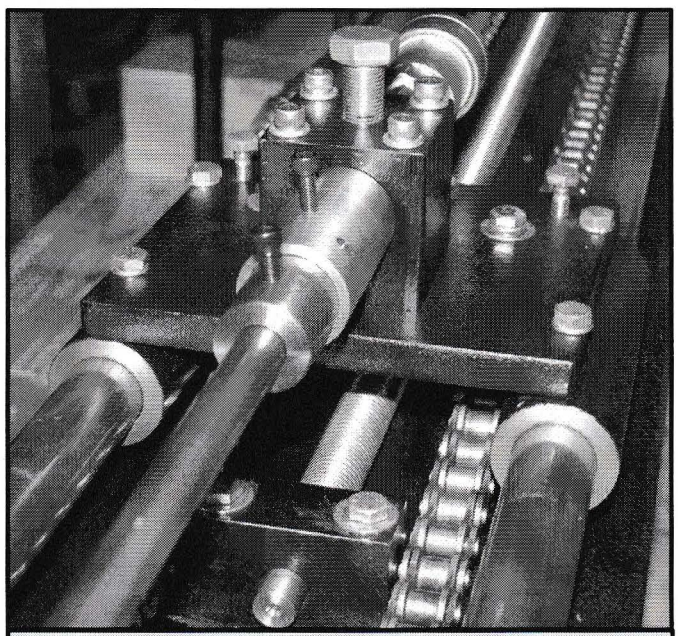
To install the reamer, the carriage is run all the way forward towards the spindle with the hand-crank. After installing the reamer driver in the tooling adapter, the reamer pull-tube is fed by hand through the outboard end of the barrel blank and installed in the



This reamer is in place and ready to do its duty.

driver. The surface of the drilled bore is about to be cut away, but you should still be careful not to scratch or burr the surface with the pull tube because the reamer's coupler will have to pass over any irregularities in the bore before the reamer can cut them away. Not only do you want to avoid causing undue wear on the coupler, you will also want to avoid any undue friction on the coupler so that unwanted vibration isn't transmitted to the reamer. To this end, I do not scrupulously clean the cutting oil out of the barrel after drilling. I wipe most of it out with a loose-fitting cleaning patch, but I leave a little to lubricate the reamer coupler's passage.

When the reamer pull-tube is in place through the barrel blank and firmly locked in the driver, the carriage is slowly run away from the spindle with the hand-crank until the reamer coupler enters the barrel. Continue traversing until the cutting sections of the reamer flutes are just about to make contact with the barrel blank. Stop at this point and lock the half-nut in place on the leadscrew. Since barrel reamers are pulled instead of pushed, flip the forward/reverse switch for the leadscrew now so that you won't forget to do it later. Before inserting the male hydraulic quick disconnect at the end of the hydraulic hose into the female quick disconnect on the universal block's tooling adapter, put all of the oil return plumbing in place at the outboard end of the barrel blank. The hydraulic hose is still full of oil from the drilling operation, so forgetting this order of setup operations will result in oil dribbling out of the reamer pull-tube and all over the floor.

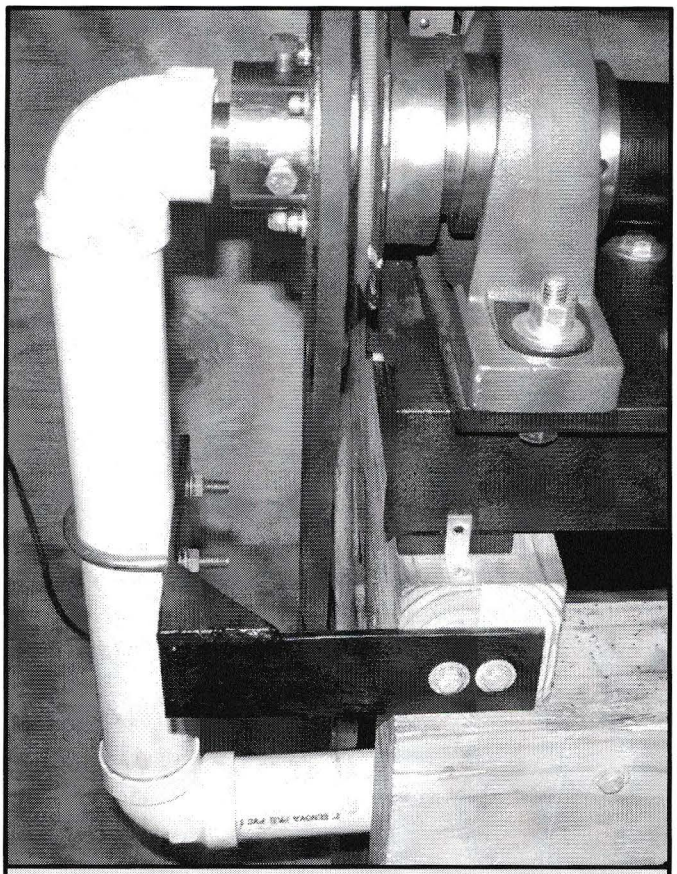


The reamer pull-tube and reamer driver are installed in the tooling adapter.

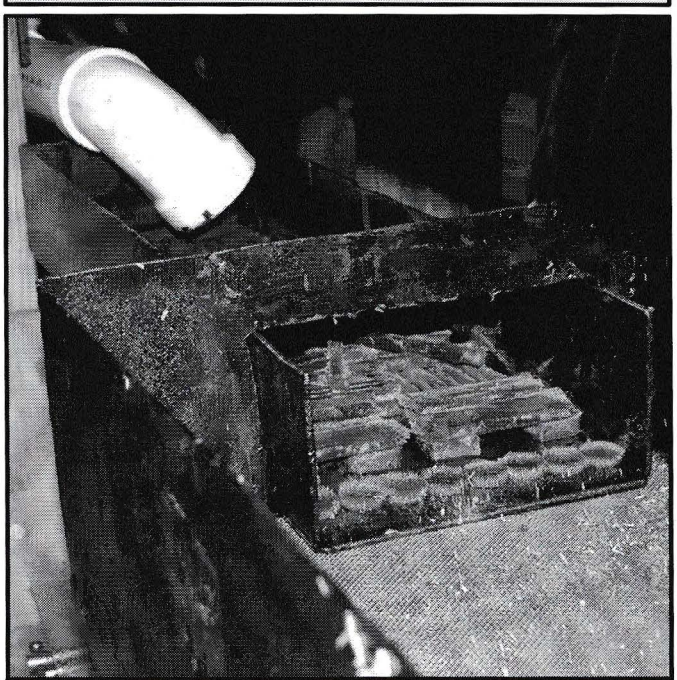
The oil collection trough is put into position first. My machine bench has a small strip of plywood screwed into position on the outside of the legs under the spindle for the trough to sit on. The trough, in turn, has legs welded to it with L-brackets that hold the trough in place on the plywood so that it can't

fall or be knocked off during the machining operation. The trough outlet is placed through the side of the chip collection basin on top of the filter screens. I designed my trough to have ½" of slope per foot towards the chip collection basin. This amount of slope keeps the oil flowing pretty well. With the trough in place, the 90° fitting of the PVC oil return pipe is put into place over the end of the barrel blank. The other end of the pipe terminates with two 90° degree fittings with a short section of pipe between them. The last fitting is angled down into the trough to make sure that the oil doesn't overshoot any of the magnets in the trough on its way back to the reservoir. This is very important because the powder-fine reamer chips can't be filtered out. Magnets are the only way to capture the little buggers. A muffler clamp is used to fix the oil return pipe firmly into position on the bracket mounted to the end of the machine bench. With all of the plumbing in place, the hydraulic hose can now be coupled into the rear of the tooling adapter assembly. If you didn't do it after drilling, now is the time to open the flow control valve all the way. Flushing away the chips from a reamer doesn't require nearly as much pressure or flow as is required during drilling, so the valve is left wide open for the duration of the reaming operation.

When it's time to begin reaming, I turn on the machine's motors in the same order as for drilling. First, the high-pressure oil system is turned on to ensure that there are no leaks anywhere. Then



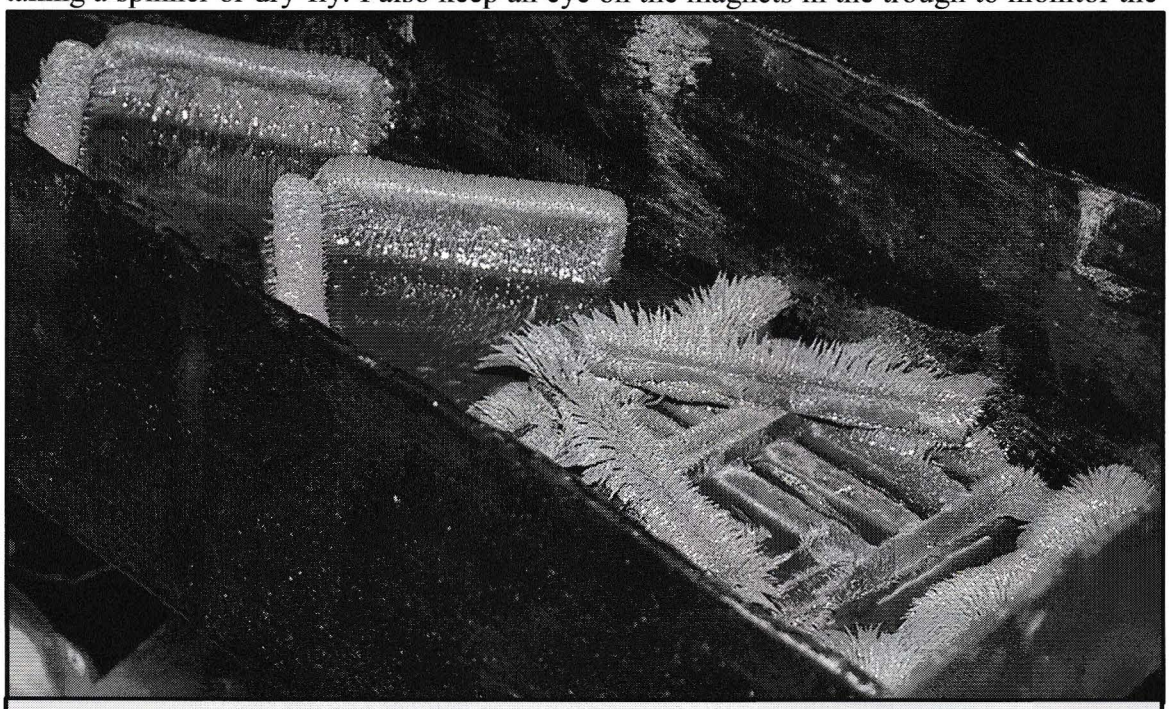
Here is the oil-return plumbing used for reaming.



The other end of the pipe dumps into a trough, which feeds into the chip collection basin.

the barrel spindle is turned on to ensure that nothing is rubbing or binding. When the other two systems are running satisfactorily, the feed system is turned on. As with the beginning of the drilling operation, there is no need to slowly ramp the speed control up to the full feed rate. Just turn the gearmotor on and twist the speed control dial to the appropriate setting. The feed rate that I use for reaming is .002" per revolution. With four cutting flutes, this amounts to .0005" of feed per flute per revolution. The normal recommended feed for reamers is .0015" to .0040" per flute per revolution, but those figures are for reamers made out of high-speed steel. Since my reamers are made out of O-1 tool steel and the finish of a rifle's bore should be exceptional, rather than average, I prefer to keep the feed rate considerably lower than the normal recommended feed. The potential pitfalls of using a very low feed rate are glazing and excessively fast cutting edge wear. I have seen no evidence of either of these conditions occurring and I feel that the final reamed finish is significantly enhanced by using a slow feed rate. There is, however, a caveat concerning this point. The free-machining 1144 steel that I use is very easy on cutting tools. If I were cutting centerfire barrels made out of 4140 steel, I would likely have to at least double the feed rate to avoid glazing and premature edge wear. This is something you will have to experiment with yourself if you intend to use chrome-moly steel.

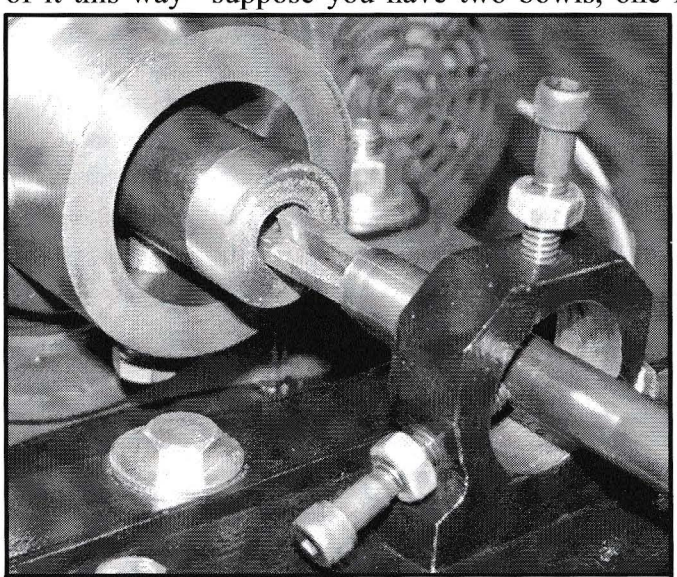
Once reaming has commenced, there is very little for the barrel maker to do in the interim. I use a flashlight to check the oil stream for chips as it returns to the reservoir. Since the interior of the bore is completely blocked from view, this is the only way to monitor the operation and be certain that the reamer is still cutting as it should. The flashlight is a very necessary aid to seeing the reamer chips. They are so small that you won't see them otherwise. But in the beam of the flashlight, they flash as they roll and tumble down the ramp like tiny little steelhead caught by a beam of sunlight in the act of taking a spinner or dry-fly. I also keep an eye on the magnets in the trough to monitor the



The reaming chips are collected by the magnet bed.

cut's progress. The whiskers on the magnets should grow at a slow and steady rate for the duration of the operation. The only failure I have ever had while reaming was due to a reamer pulling out of the coupler. This was the first reamer assembly that I ever made and, foolishly, I did not tin the reamer shank and the interior of the coupler before assembly. I just tried to flow the solder in between them after they were put together. To say that the solder flow was incomplete would be a drastic understatement. But that reamer still managed hang on long enough to ream two barrels before it pulled out in the third. Since I changed my technique to include tinning before assembly and the use of flux-core solder after assembly, I have had no further problems with reamers going AWOL. The reason I bring this up here is that the only way I could tell something had gone amiss was by noting that the migration of miniature steelhead swimming downstream to the reservoir had abruptly stopped. So it *is* worth monitoring the chip load in the cutting oil while the reamer is doing its thing.

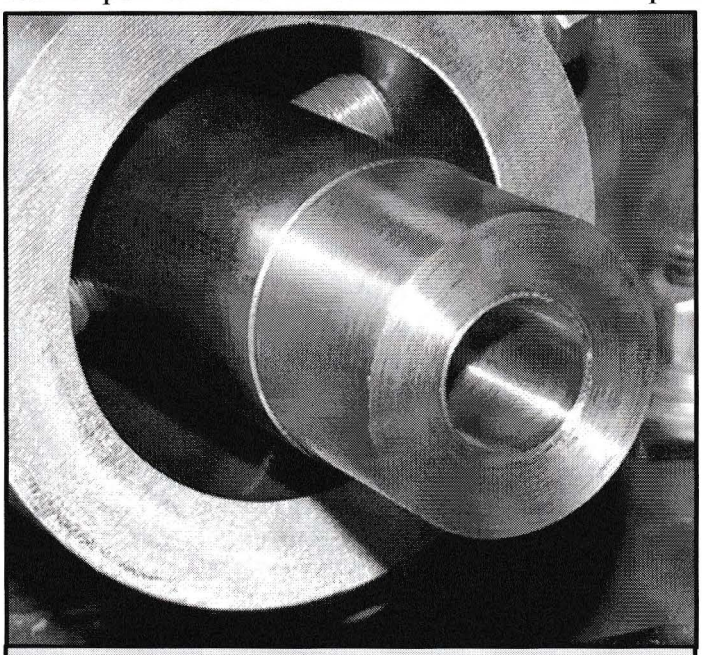
I have found that it is very beneficial to ream a barrel blank as soon after the drilling operation is complete as possible. As stated previously, the cutting oil will get quite warm during the drilling operation. This latent heat makes the oil thinner which, in turn, makes it far easier to pull out the tiny reaming chips with magnets. If the oil is allowed to cool between the drilling and reaming operations, it will remain relatively cool throughout the entire process because reaming doesn't cause nearly as much friction-induced heating as drilling does. The little chips simply can't plow through cool, thick oil as quickly as they can when its temperature is elevated and its viscosity is reduced. Think of it this way– suppose you have two bowls, one filled with water and the other filled with maple syrup. If you drop a pebble in the bowl filled with water, it will immediately drop straight to the bottom of the bowl because the water is so fluid that it offers little resistance to the pull of gravity. By contrast, drop the same pebble in the syrup and it will fall in slow-motion to the bottom of the bowl because the syrup is too thick to be displaced rapidly by the relatively weak pull of our planet's gravitational field. The exact same principal applies to the reamer-cut chips when under the influence of a magnetic field. They will obey the laws of physics, they just won't be able to do it with much urgency if hindered by a viscous fluid.



The residual oil left in the barrel after shutting off the pump motor tends to flush the chips out and make a bit of a mess as the reamer exits the bore.

When reaming, there is no need to index the starting position of the carriage with electrical tape to take measurements as the operation proceeds. All that is required is for the barrel maker to pay attention to what the machine is doing. When the leading edge of the reamer coupler appears at the far end of the barrel blank, that is the time to start measuring. A steel rule is used to measure the growing length of the reamer coupler that

is protruding from the barrel. When the coupler is ⅛" shy of exiting the barrel blank completely, the oil pump is shut off. At this point, I also turn the lower screws of the steady rest until the tips of the screws make *very light* contact with the reamer pull-tube. Because the reamer still has an inch of travel left at this point, it will begin to squeal a bit in protest to having its lubrication cut off. But there will be enough residual oil left in the reamer pull-tube and the barrel blank itself to keep things running relatively smoothly as the reamer finishes its cut. However, the chips will not be flushed away from the cutting edges efficiently and the last inch of the bore will not have as smooth a finish as the rest of the bore. This is yet another reason why it is recommended that the last inch of the bore be cut off after the rifling operation is complete. As the reamer finally exits the finished bore, the screws of the steady rest take the weight of the reamer assembly and prevent any type of bouncing or flexing maneuvers that it might otherwise be tempted to engage in. This ensures that the cutting flutes of the reamer won't end up getting chipped by making sudden contact with the face of the barrel blank.



Note the slight roughness in the reamed bore; this is the section of the bore that was reamed with no support from the coupler and no lubrication. The rest of the bore is much better. This section will be cut off later to form the muzzle.

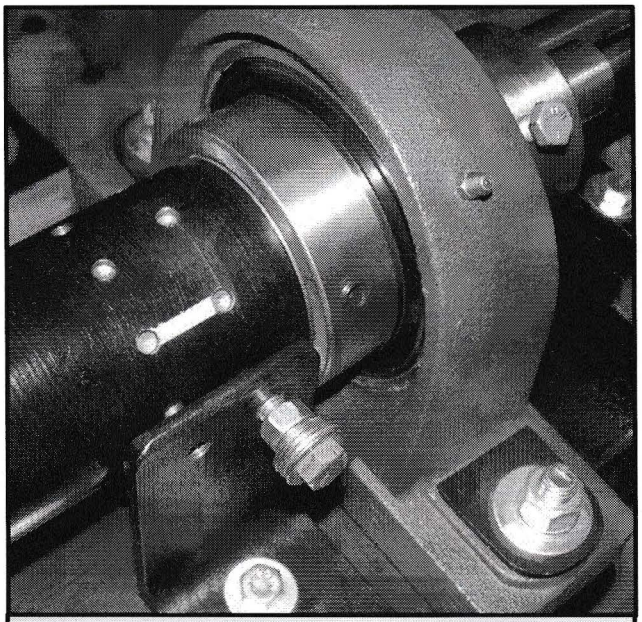
After turning off the leadscrew and spindle, the hydraulic hose is disconnected and the half-nut is released from the leadscrew. The carriage can now be moved back with the hand-crank to allow room for removing the reamer pull-tube from the driver. As with the deep-hole drill, the reamer assembly is then placed through the top of the machine bench to stand vertically in the chip collection basin so that the cutting oil can drain out of it. The barrel blank is left in place in the barrel spindle for the rifling operation. But before rifling, I do swab all of the cutting oil out of the bore so I can have a look at the reamed finish. If the reamer assembly was put together perfectly straight and the cutting flutes were properly sharpened, the interior surface of the barrel blank should be literally mirror-bright at this point. Because this is a machined finish, there will be very light tool marks encircling the bore. However, if everything was done correctly, these tool marks will be exceedingly shallow. The surface of a freshly reamed bore, if viewed in the right light, should have basically the same rainbow appearance as the data-storing surface of a CD or DVD. The refraction of light on the disc's surface is caused by the miniscule dimensional irregularities that allow the object to store information. The same is true of the very light irregularities of the machine-cut surface of the bore and they scatter light for the exact same reason. A sharp, well-aligned reamer should cause dimensional irregularities of the bore's surface that are of about the same magnitude as

the roughness of a CD's surface (the actual data-storing surface, not the clear topcoat surface that is applied to protect the information from abrasion). In other words, it should be pretty darn smooth! If yours is, congratulate yourself for a job well done and then take a well-deserved break, because the *real* work of making a rifle barrel is about to begin and you need to mentally prepare yourself for it.

Rifling

The drilling and reaming of a rifle barrel are standard machining operations. While they do require sharp cutting tools and a proper setup, they do not require any special skills above and beyond the basics that can be learned in a high school metal shop class. Rifling, on the other hand, requires a degree of finesse and a level of concentration that is beyond the basics. While setting up the operation correctly and using quality tools is still vitally important, the act of removing steel with a rifling cutter box is a horse of a different color compared to every other machining operation (or, at least, every other machining operation that I have ever undertaken). There is almost a symbiotic relationship between the barrel maker, the hook cutter and the barrel blank when rifling, for the three must operate as one. Both the cutter and the barrel will provide constant feedback to the barrel maker during each successive cut and the barrel maker must be completely focused on these signals. Each action that the barrel maker takes while rifling is based entirely upon the feedback he received from the tooling and the workpiece during the preceding cut. This intricate interplay between workpiece, tool and craftsman is what makes rifling a barrel more of an art than a science. Each cutting pass through the bore of a rifle barrel provides the barrel maker with subtle, yet extremely important, tactile cues that will tell him how the cut is proceeding and what action may be necessary on his part before the commencement of the next cut. Failure to perceive these cues and react accordingly will result in failure of the machining operation. Because the feel of the cut is all that the barrel maker has to guide him, the act of rifling a barrel is far closer kin to draw-filing an octagon barrel profile than it is to drilling or reaming. The main difference, of course, is that you can actually *see* what you're doing when draw-filing. The luxury of sight is almost entirely absent from the rifling operation. When you gaze through the bore of a properly cut-rifled barrel, you are witness to the handiwork of a man who knows the intricacies and subtleties of steel as well as he knows his own quirks and foibles.

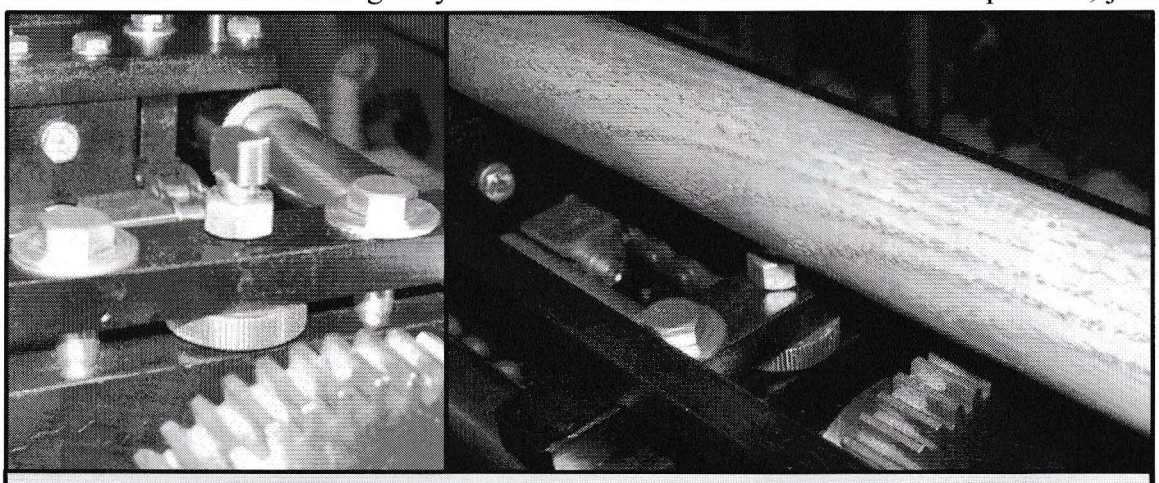
But before we can unravel the mysteries of rifling a barrel, we have to get the machine and tooling set up to make the cuts. Since the rifling operation will be executed in its entirety under manual power, the first step is to remove the drive belts from the spindle and spindle motor. This really isn't required, but it's much easier to turn the spindle by hand if you're not also turning the motor windings. And if, like me, you end up using the drive pulley on the spindle as a convenient hand-wheel to turn the spindle, removing the drive belts will also preclude the possibility of getting your fingers stuck between the pulley and the drive belt with all of the attendant stomping and cursing that such an event inspires. Once the spindle has been rendered harmless to your tender phalanges, the set-screw is installed in the groove indexing fixture. The screw tip is indexed into the starting index hole in the spindle and turned hand-tight to set the barrel blank for the first pass of the rifling cutter box. Do not, under any circumstances, forget to index the barrel blank at the starting point *before* installing the rifling cylinder and



The spindle is indexed in the hole denoted by the white line prior to beginning the rifling operation. Every time the spindle comes back around to the white line, the cutter is raised for the next cut.

rifling cutter box on the machine. The last thing you want to do is ruin the workpiece before you've even begun to make it look like a rifle barrel.

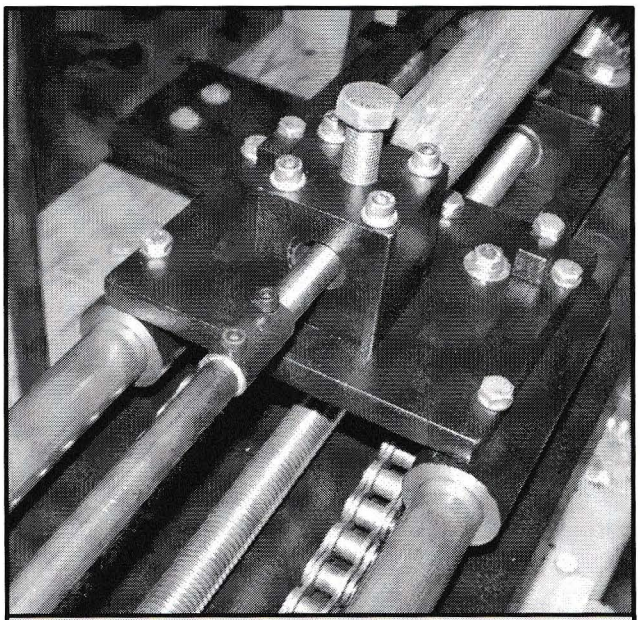
When you're certain that the barrel is indexed into position to begin rifling, remove the tooling adapter from the universal block and insert the bearing into the back of the universal block. At this point, the carriage should still be at its furthest position away from the spindle following the reaming operation. Using the hand-crank, move the carriage forward a few inches and then slide the rear carriage all the way to the end of its travel (away from the spindle). This will provide the clearance between the carriages that is necessary to place the rifling cylinder, and its axles, between them. Check the height of the rifling cylinder's indexing shoe and adjust its height as necessary to fit fully into the groove of the rifling cylinder without bottoming out. Do not tighten the lock-nut on the shoe just yet. The angle of the shoe will need to be set in the groove before locking it into position. After sliding the nylon spacing washers onto the cylinder axles, the rear axle of the rifling cylinder is inserted through the bearing in the rifling cylinder block and the cylinder is lowered into position with the groove engaging the indexing shoe. Now, while holding the rifling cylinder in place, move the forward carriage back while simultaneously inserting the cylinder's forward axle through the universal block's bearing. If you can't reach the hand-crank from this position, just



On the left is the rifling cylinder shoe. The rifling cylinder is installed while the shoe's lock-nuts are loose so that the angle can be properly set for the twist of the cylinder. After the cylinder is installed, the lock-nuts are tightened to hold the shoe in position.

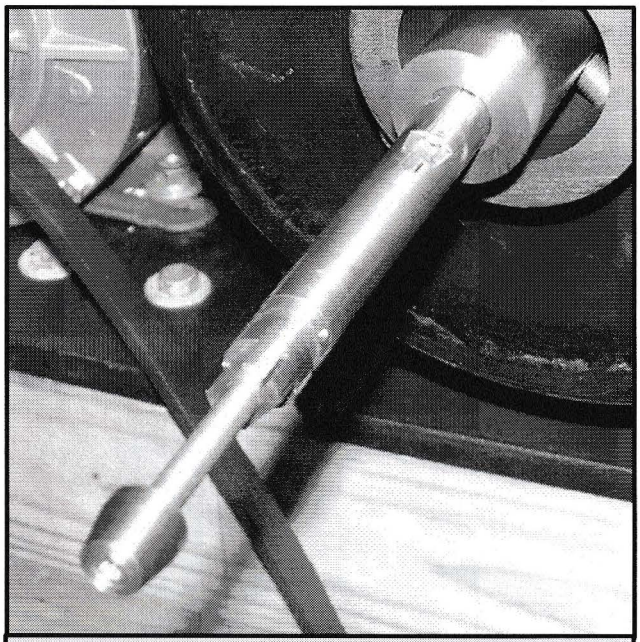
pull the carriage with your hand until the bearing butts firmly against the nylon spacer. With the rifling cylinder now fully supported, the rifling cylinder straps are installed between the two carriages to bind them together as a single unit. The lock-nut on the indexing shoe can now be snugged down to lock in the angle of the indexing surface. Use the hand-crank to run the carriages back and forth a few times. If the shoe is binding on the sides of the cylinder's groove (it won't, if the groove is uniform) adjust its angle until it no longer binds. More importantly, you want to verify that the shoe is not bottoming out in the groove. As mentioned previously, this condition will cause enough additional drag on the cylinder to cause the rifling to assume a slightly wavy configuration. If the shoe is rubbing the bottom, you will be able to see a slick, shiny spot in the bottom of the groove after a few passes back and forth. If this occurs, remove the cylinder from the machine and adjust the height of the shoe by turning it a half-thread deeper into the bed bar strap clamp before proceeding with the rifling operation.

With the rifling cylinder in position and running smoothly, crank the dual-carriage assembly all the way to the rear (away from the spindle). Then slide the steady rest back, close to the forward carriage. Rifling is the one machining operation during which I have actually found an important function for the steady rest. Before installing the rifling cutter box's pull-rod on the front axle of the rifling cylinder, I slide a simple, round guide bushing over the pull-rod. The screws of the steady rest will hold this bushing to keep the rifling cutter box on the centerline of the bore at the rearward-most point of its travel. But for now, just insert the pull-rod through the steady rest and affix it to the cylinder axle with its set-screw. Now the dual-carriage assembly is cranked forward *slowly* with one hand while the other hand supports the rifling cutter box. Stop the carriage movement when the rifling cutter box and the feed adjustment ramp stem are both still completely clear of the end of the barrel blank by a bit. The steady rest is now slid forward until it is just short of the cutter box and its set-screw is hand-tightened onto the bed bar. Now continue cranking the carriages forward until the rifling cutter box just barely enters the end of the barrel. At this point, stop and firmly tighten the steady rest set-screw down to anchor the rest. Slide the pull-rod bushing to the center of the steady rest and adjust the screws that actually form the rest into contact with the bushing and tighten them down. You should now be able to crank the rifling cutter box in and out of the bore without using your hands to guide it because the bushing is holding it on the centerline. If the cutter box bumps the lip of the bore even slightly as it enters, adjust the steady rest screws until it does not.



The rifling cutter box pull-rod is attached to the rifling cylinder axle with a set-screw. Make absolutely sure that this screw is very tight.

The rifling setup is now complete and you are ready to start making the magic happen. Retract the adjusting ramp from the cutter box as far as possible to drop the cutter, and then crank the carriages forward until the rifling cutter box emerges from the far end of the barrel. If you have cut your pull-rod to the proper length and set up the barrel in the spindle properly, the tail end of the rifling cutter box will remain in the bore. This is what you want. If your pull-rod is long enough to allow the cutter box to drop out of the barrel blank, put some type of travel stop in place to prevent the carriages from traveling far enough for this to happen. The hand-crank is far enough from the outboard end of the spindle that you will not be able to guide the rifling cutter box back into the barrel manually. It will have to be self-guiding. If you haven't already done so, turn the feed adjustment nut down the stem until it is snug against the ramp retaining nut. With the ramp now held in its most rearward position, use a dial caliper to measure from the bottom of the rifling cutter box to the top of the hook cutter. This will give you a rough idea of how much ramp feed is required to make the first cut. For instance, if you're making a 58 caliber muzzleloader barrel (.5800" across the lands) and this measurement turns out to be .576", the cutter will need to be raised .004" to begin cutting the rifling. In our hypothetical example, I would retract the feed adjustment nut three threads (.003" of cutter height) and then crank the cutter box slowly into the bore to see if the cutter will bite yet– it shouldn't. From this point, the height of the cutter is raised .0001" at a time and the cutter is fed an inch or so into the bore after each incremental height adjustment until the cutter will begin to bite. When the cutter bites enough to just barely scuff the bore, stop adjusting! This is the proper setting for the first pass of the cutter. Do not, under any circumstances, raise the cutter a few ten-thousandths of an inch to "get things off to a good start". Making a heavy initial cut will put more torque on the pull-rod than subsequent cuts, causing it to twist a bit more than it should. This is not a good way to begin a delicate operation like rifling a bore. Start cutting the grooves slowly and don't worry about how much material is being removed at this point. It is far more important to properly establish the twist rate than it is to get off to a fast start. Incidentally, when establishing the proper cutter height to begin the operation, it is perfectly permissible to run the cutter box backwards without lowering the cutter. This is so because the cutter is not actually in contact with the bore yet. However, after first contact is made, never run the cutter box backwards without dropping the cutter. Doing so will cause excessive and completely unnecessary wear on the top of the cutter.

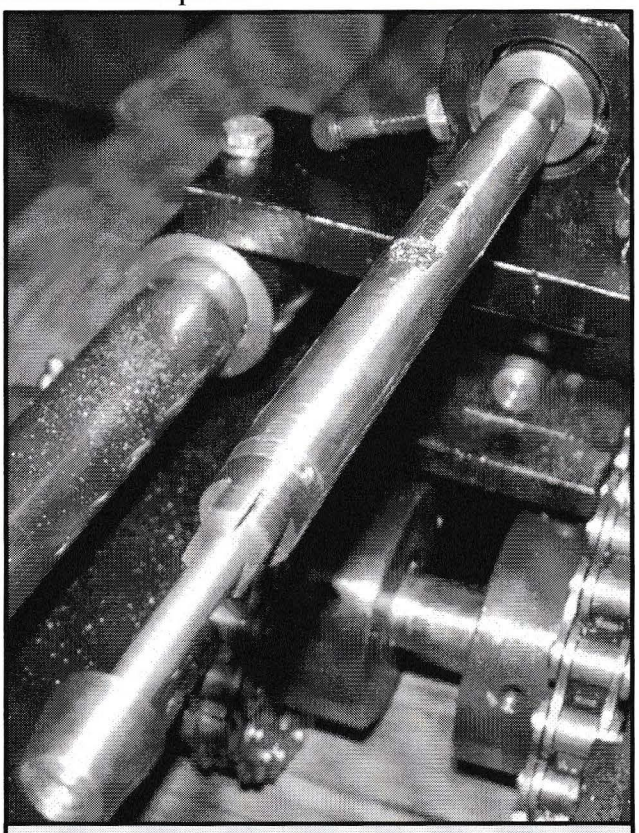


The rifling cutter box in position and ready to have the cutter set for the first cut. Note the snug fit between the cutter box and the barrel's bore.

As for the speed of the cut, it *is* possible to pull the rifling cutter box through the bore too fast by hand. In basic machining terms, rifling is nothing more than a very specialized planing operation. The recommended speed for planing with high-speed steel cutting tools is 25 to 40 fpm for steels alloys with appropriate hardness ratings for use as rifle barrels. My own 1144 barrels dictate a cutting speed of 40 fpm. Since the total travel of my carriage assembly is roughly four feet, it will take me six seconds to pull the rifling cutter box through the barrel blank and out the other end when I'm using the correct cutting speed. It is a very good idea to actually count (one-Mississippi... two-Mississippi...) as you're drawing the cutter box through the barrel for the first few dozen passes. Once you get into the rhythm of the cut, counting will no longer be necessary. You will be able to tell by the sound and feel of the cut whether or not the cutting speed is right. Trust me, you will get so much practice at gauging the cutting speed when rifling that you will be a bona-fide expert on the subject by the time your very first barrel is complete. Just make sure that you're not cutting too fast. When scraping off a mere .0001" on each pass, there is very little pressure forcing the cutter into the workpiece and it doesn't take much abuse to render the hook cutter too dull to cut such an insignificant shaving.

This brings us to the feed, or depth, of the cut. It is very tempting to cut the rifling in larger increments. In fact, if you research the subject, you will find that the cut-rifling machines of a century ago cut grooves a full .001" deeper on each successive pass of the cutter. However, if you do your research thoroughly, you will also find that those machines used hydraulics to power the cut and lapping the barrel after rifling was a *requirement* to obtain a satisfactory finished product. I have experimented with heavier-than-standard cuts, but I found that this caused more problems than the small amount of time saved was worth. For one thing, tripling the feed to a still paltry .0003" caused the force required to make the cut to increase so drastically that I had to use *both hands* on the hand-crank to get the cutter box through the barrel. This is an excessive amount of force that my machine was not designed to handle, at least not if I want it to continue to cut accurately. Worse, because I have to switch hands from one crank handle to the other for the cut to proceed, the cut is made in a herky-jerky fashion that is not conducive to nice, smooth-flowing spiral grooves. Heavy cuts also invariably leave the groove bottoms very rough; so rough that lapping would be mandatory if this practice was continued. When light .0001" cuts are made for the duration of the rifling operation, lapping is an option, not a requirement. I also found that heavy cuts fill the chip relief slot to the point of overflowing about halfway through the barrel. Once the slot is full, the pressure exerted by the chips will force the hook cutter down and away from the bore. In order to maintain uniform grooves cut to the full depth of each cutter setting, the cutter must be drawn through each groove twice to achieve a full-depth cut with a .0003" feed rate. This negates any time savings, and saving time was the sole purpose of making heavy cuts in the first place. On the positive side of things, the cutter doesn't need to be sharpened nearly as often with .0003" cuts, but that is the only benefit that I have found. That minor improvement doesn't even come close to being worth all of the headaches that heavy cuts cause, so I strongly recommend that you stick with the saner, more practical .0001" feed rate.

At the end of each cutting pass, the rifling cutter box will emerge from the end of the barrel blank with the chip relief slot packed full of chips. I keep a small, stiff bristled paint brush handy to sweep the chips away from the hook cutter for the next pass. Then the adjusting ramp is retracted to drop the cutter for the return stroke. I also use an acid brush dipped in cutting oil to lubricate the cutter before running it back through the bore. Once the cutter box is returned to the starting position, the indexing set-screw is removed from the spindle, the spindle is advanced to the next indexing hole and the set-screw is turned back in snugly. The adjusting ramp is then pushed back into the cutter box until the feed adjustment nut butts firmly against the retaining nut. I like to keep my finger on the end of the stem and hold a bit of pressure against it while cranking the cutter box back into the bore to ensure that the ramp remains at full depth as the hook cutter bites into the barrel blank once more. Once the hook cutter is in the bore and cutting, the pressure of the cut holds the ramp in place and keeps the cutter at full height. This procedure is repeated for every groove of the barrel until coming back around to the starting groove. Before making the next pass in this groove, the feed adjustment nut is given a tenth of a turn to the next indexing mark to raise the cutter another .0001" over the previous setting. It doesn't take long for the rifling operation to become a steady rhythm of cycling the rifling cutter box back and forth and work will proceed at a pretty fair pace. It is very important to concentrate solely upon the feel and sound of the cutter in the bore of the barrel. Do not allow anything else to distract you. Once the rifling operation is under way, you should make every effort to keep the cut progressing smoothly while you've got the feel of the barrel. The only good reason to stop is to sharpen the cutter.



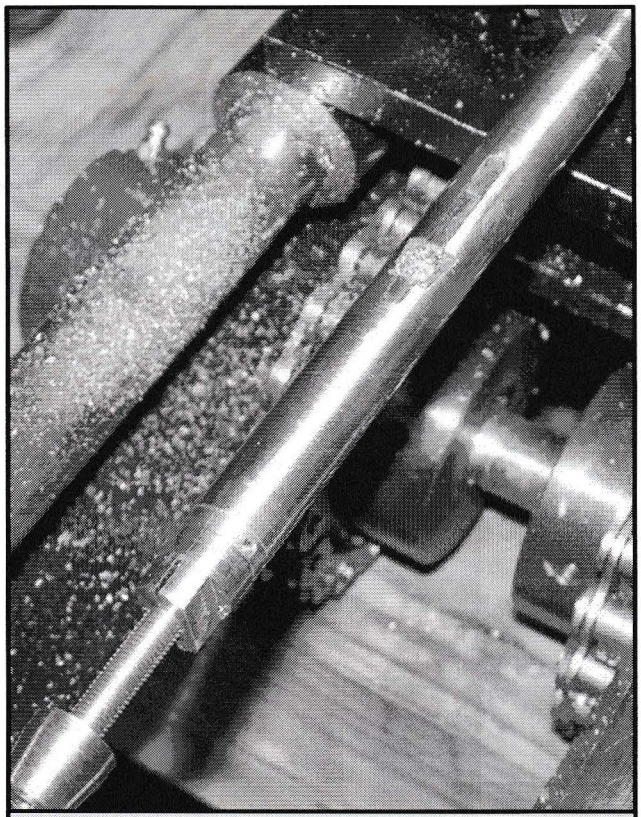
The chip relief slot is filled to the brim by the chips from a .0001" deep cut at the end of a cutting stroke. Also note the pull-rod guide bushing centered in the steady rest.

There is no need to visually inspect the cutter between passes to monitor the quality of the edge. When the cutter gets dull, it will be very apparent by the feel of the cut, the sound of the cut and the skimpy chip load in the chip relief slot at the end of that particular pass. It has been my experience that the cutter does not slowly diminish in its ability to cut. One pass will be exactly the same as all of the others. Then, on the very next pass, you will be able to feel and hear the cutter slide in the groove instead of cutting and the chips produced by the cut will be very small and few in number. This is the time to stop and sharpen the cutter. The cutter is raised into position for sharpening by rolling

the ramp around so that the cutter comes up on the round portion of the ramp body. I use a small, fine-grade square India stone to sharpen my cutters. I sharpen by placing my finger on the side of the stone and pushing forward to stone the cutting face back. Don't use downward pressure or you will cut into the chip relief slot and ruin the 90° angle that was established when the cutter was made. Stone the cutter face in a back-and-forth fashion for several strokes and then inspect the actual cutting edge with a bright flashlight. If the cutting edge is still dull, it will gleam brightly in the flashlight beam. Continue stoning the cutter until that bright, silver line at the very edge of the cutting surface disappears completely and the cutter will be sharp. But don't try to proceed with the next cut just yet. The act of sharpening the cutter will raise a very tiny burr on the cutting edge. And with a cutting depth of .0001", the tiniest burr that you can imagine can and will interfere with the cut and cause the cutter to skip. To remove the burr, rub a small brass rod along the edge in the direction of a normal cut. Apply plenty of pressure and make sure that the full length of the cutting edge touches, and removes, plenty of brass. It seems somewhat counterintuitive that brass can remove the burr when the steel of the barrel blank will not. But the key here is cutting pressure, not material hardness. If you apply enough pressure to the brass to make a cut .003" or so deep, the pressure of the material rubbing against those microscopic burrs will be far greater than the pressure of a normal rifling cut and the burrs will flake off with the brass chips. Before returning to the rifling operation, I also like to use a triangular stone to make a few passes in the relief groove at the base of the cutting face of the hook cutter. If this isn't done, the face will eventually be stoned back far enough to completely remove the relief groove and that can cause interference with the corner of the square stone used to sharpen the cutter. Any interference of that sort can cause the rake angle of the cutting face to change and that would be detrimental to the quality of the cut.

It is literally impossible to overstate the importance of keeping the hook cutter sharp. Any degree of dullness will cause the cutter to skip in the bore instead of cutting as it should. This is clearly evident in the fact that a freshly sharpened cutter will only cut for 10 to 15 passes of the rifling cutter box through the bore. After that, it will abruptly stop cutting. Of course, the cutter is still quite sharp by normal standards, certainly sharp enough for conventional machining operations. But perfect sharpness is required for rifling simply because the cuts are so light and there is so little pressure involved. Any imperfection of the cutting edge will be sufficient to impede the cut. Impediments to the cut will also come in the form of wear on the top-relief of the cutter. Every third time I stop to sharpen the cutter, I check the top-relief before stoning the face. The top-relief angle is painted with a black permanent marker and then one more pass is made with the cutter in the same groove that it just passed through without cutting. The objective here is not to remove steel from the barrel. I just want contact with the groove to remove the ink from the top of the cutter at the point of contact. If the top of the cutter is making contact with the bore over an area more than .003" wide, the relief angle will need to be dressed to prevent it from interfering with the cut. To dress the relief angle, I once again paint the top of the cutter with a marker. A dry sharpening stone (stoning oil will wash away the ink) is then used to carefully stone the relief angle evenly. *Do not stone the portion of the cutter that is actually rubbing the bore.* Stone the original relief surface evenly down until it removes the worn area and the top-relief once again meets the face. I do not make more than three or four strokes with the stone without stopping to re-blacken the relief

angle so that I can continue to see what I'm doing. This is the only way to stone this surface by hand without changing the arc of the surface. Continue stoning until the only thing left of the previously worn portion of the relief that was contacting the bore is an ultra-thin black ink line. And, once again, use a bright flashlight to make absolutely certain that you can clearly see what you're doing. Remember that the top edge of the cutter determines the shape of the grooves, so if you screw up and stone it lopsided, the groove bottoms will also be askew.



About halfway through the process... the chip relief slot is still full, indicating that the cutter is sharp and a full cut is being made. As you can see from the chips scattered everywhere, I make quite a mess when rifling.

Because of the frequent sharpening that is necessary to cut rifling, the hook cutter won't last very long. The most detrimental thing about sharpening the cutter is dressing the top-relief. This procedure shortens the cutter by about a thousandth of an inch every time the dressing is performed. Because the vertical travel of the cutter is fixed by the adjusting ramp height, the cutter will eventually become too short to cut the grooves to full depth. When you notice that you are just about to run out of adjustment threads on the ramp stem after completing a barrel, you had better make a new cutter before starting another barrel or the cutter may literally come up short, leaving you in a pickle with a half-rifled barrel. You'll then find yourself in the unenviable position of fabricating a new hook cutter and trying to install it in the rifling cutter box while it's in place on the rifling machine. Or, you can remove the rifling cutter box from the machine to install the new cutter and run the risk of not being able to get it realigned perfectly with the barrel blank after the new cutter is installed. Personally, I'd rather play it safe and install a new cutter between rifling operations while the old one still has a bit of life left in it. The exact amount of life that you will get from each cutter will depend upon the number and depth of grooves you are cutting. For example, I cut either 8 or 10 grooves in my muzzleloader barrels (depending on the caliber) and the grooves are cut to a depth of .008". For a ten-groove barrel, this amounts to 800 cutting passes per barrel. At this rate, I can rifle 3 barrels with a particular cutter before I decide that it's best to just go ahead and replace it. If, on the other hand, I was using the same exact cutter to make centerfire barrels in 243 caliber with 5 grooves cut to .003" deep, I would be able to rifle 16 barrels before the cutter would need to be replaced because I would be making a mere 150 cutting passes per barrel. Suffice it to say that you will

become far more familiar with the process of fabricating hook cutters if you want to make muzzleloader barrels than you will if you stick with centerfires. For those of you who think that custom, large-bore muzzleloader barrels are too expensive, look again at the figures above. Note carefully that, by the time I have completed the rifling in *one* 8-bore barrel, I could have rifled *five* .243 Winchester barrels and gotten a good start on number six.

Measuring the progress of the rifling operation is very important, especially with barrels intended for high-pressure centerfire cartridges. If rifling is stopped before the grooves reach full depth, chamber pressures in the finished barrel can become dangerously high, even with factory loads. By the same token, cutting the grooves too deep can result in gas blowing past the bullet. This will have a negative effect on velocity and may also lead to erosion of the bore. Despite these indisputable truths, production tolerances for commercial and military barrels can be surprisingly lenient. The tolerance for both land diameter and groove-circle diameter for most calibers is ±.002" and the tightest tolerance specs I have seen call for ±.001" (check the individual specs for the caliber you intend to make). No wonder reloading manuals stress the importance of low-pressure starting loads that are slowly increased to maximum while keeping a wary eye out for signs of excessive pressure. Those tolerances allow for a lot of barrel-to-barrel variation. One source lists the following specifications for .303 British military rifle barrels (.312" bullets): bore diameter .303" to .305" and groove depth .005" to .008". According to these specs, if both minimum bore diameter and minimum groove depth exist in the same barrel, the resulting groove-circle diameter will be .313". The important thing to note about this set of tolerances is that it is much better (in terms of pressure and safety) to cut a rifle bore slightly oversize than to leave it slightly undersize. It's better to suffer the loss of a little bit of velocity and accuracy than it is to suffer the loss of a lot of skull and brain tissue because your barrel blew up in your face. The use of soft lead slugs that are bumped up in the bore and subsequently measured is the time-honored way to measure the progress of your rifling. This method still works well. The use of some sort of tee-gage fabricated specifically to measure rifle bore diameter can usually provide a little more accuracy. No matter what method you use to measure your bore, it's definitely best to err on the side of caution. If in doubt, make a couple more passes with the rifling cutter box and then measure again. You can live with rifling that is cut a couple ten-thousandths of an inch too deep, but you might not be living at all for much longer if you squeeze the trigger of a rifle equipped with a barrel bore that's cut too shallow. As for my own barrels, I have found that, with their spacious bores, measuring large-bore muzzleloader barrels with the knife-edge portion of a good set of dial calipers is just as accurate as slugging the bore. I can easily measure and cut to a tolerance of better than ±.002" of the desired groove-circle diameter by this method. This is certainly enough accuracy for muzzleloader barrels that either grip a cloth-patched round ball or engrave the rifling into a conical bullet upon loading. The important thing with muzzleloaders is that you make sure that the grooves are deep enough to properly spin their relatively heavy projectiles. It would be very easy (and very tempting) to call it quits and stop rifling before the grooves reach full depth. Conversely, it would be difficult to cut them too deep to be accurate and nearly impossible to cut them too deep to be safe. The same can't be said for centerfire barrels, so if you intend to make them, you will have to voluntarily hold yourself to higher standards. But with a little patience, forethought and

careful measuring, you shouldn't find it difficult to make barrels that meet or exceed the dimensional production tolerances for your chosen caliber. Especially considering the fact that you just built your own barrel machine and fabricated the associated tooling completely from scratch! Measuring a rifle's bore is small potatoes compared to that.

That's it folks. You are now fully armed with all of the information you need to begin making your own rifle barrels. The only thing left to discuss is the matter of lapping barrels. As I've said many times throughout this book, a properly cut-rifled barrel does not *need* to be lapped. However, there may be some minor benefits to be gained from the lapping procedure. The most indisputable argument in favor of lapping is the one that says that lapped barrels don't foul as quickly as un-lapped barrels. This is true. Lapping tends to smooth the transverse reamer tool marks and this simply must reduce the amount of bullet jacket material that gets scrubbed off onto the surface of the bore. However, lapping shouldn't be overdone. After spending hours or days making a rifle barrel to the tightest dimensional tolerances possible, you don't want to run the risk of lapping the symmetrical uniformity right out of a brand-new barrel. At least I don't care to risk it. In terms of the accuracy of the finished barrel, I doubt that lapping will provide any real benefits unless subsequent machining operations cause distortions in the bore. If dovetail cuts are milled in a thin-walled barrel for the installation of iron sights or some other accoutrement, the milling operation can squeeze the barrel down just a bit. Screwing a barrel with slightly oversized threads into a receiver can cause similar distortion, especially in revolver barrels. These types of tight spots in the bore can distort projectiles and distorted projectiles tend to fly off course. So it seems to me that a properly cut-rifled barrel is best left un-lapped until its installation on the rifle is complete. Then, the bore can be slugged to see if any tight spots have been created during fabrication or assembly and lapped out if found to be present. If the bore isn't distorted somehow during the construction of the rifle, then lapping shouldn't be necessary at all. But there are a whole host of folks who will strongly disagree with that opinion and will further opine that lapping is never a bad idea and that *every* barrel should be lapped for top performance. I would suggest that you experiment with lapping and make up your own mind. If you feel that the procedure provides real benefits, then, by all means, lap your barrels as a standard procedure. That's the greatest thing about making your own barrels; you can make them any way you please (within the bounds of safety and common sense, of course).

CHAPTER 8: Understanding Barrel Steel

The sole purpose of a rifle barrel is to accurately propel a projectile towards the target. The barrel accomplishes this feat by containing and channeling a tremendous amount of pressure behind the projectile. If the steel used to make the barrel can't handle the pressures involved, the high-pressure gas will find its path of least resistance out through the barrel wall instead of down the bore behind the bullet. Not only would this defeat the purpose of the barrel by resulting in a projectile that does not project from the rifle, but this situation is also extremely dangerous for the shooter and any hapless bystanders who find themselves in the wrong place at the wrong time. Because the pressures involved with firing a rifle are so potentially dangerous, the choice of steel used to make the barrel is not a decision to be taken lightly.

But strength is not the only property of barrel steel that matters. The barrel blank must also be springy enough to expand slightly under pressure and then snap back into shape after the projectile has exited the bore and pressures have returned to normal. This means that the barrel steel must not be too hard because it will then be too brittle to handle repeated high-pressure expansion. To really top things off nicely, a barrel steel should also be reasonably easy to machine. The strongest, toughest barrel blank in the world will do you little good if it's so ridiculously hard to cut that it's nearly impossible to machine smooth lands and grooves into it.

In this chapter, we will take a detailed look at several grades of steel that are appropriate for both muzzleloading and centerfire rifle barrels. But first, we need to know why we are looking at these steels and not others. So we will begin by determining the general physical properties required of any barrel blank. Then we will look at the hardening and tempering processes that allow our chosen alloys to exhibit these necessary physical properties. Finally, we will look at the chemical composition and physical properties of five different alloy types so that we can compare and contrast them during the process of selecting the best steel for our purposes. As we will see, the barrel maker is often left with some very tough choices to make when choosing a barrel steel alloy.

Physical Properties of Barrel Steel

Barrel steels must meet or exceed certain minimum physical property requirements to be deemed suitable for the intended application. As mentioned above, the steel must be simultaneously strong, tough, hard (but not too hard), and relatively easy to cut. For rifles that will be either blued or browned, the steel must also be fairly easy to oxidize or it will be very hard to color to the desired finish. If these general characteristics are to be anything more than subjective hogwash, we must quantify exactly how much strength, toughness, etc. we are talking about.

Minimum Requirements for Muzzleloading Rifle Barrels

The original, timeless standard for the physical properties required of a muzzleloader barrel is wrought iron. This was the first ferrous material used to make rifle barrels and there are still a few dedicated artisans who forge their barrel blanks from iron. Any modern steel alloy used to make a muzzleloader barrel must be able to measure up to, or exceed, the mechanical properties of wrought iron.

Mechanical Properties of Wrought Iron

Hardness, Brinell	105
Hardness, Rockwell B	62
Hardness, Rockwell C	Can't be measured on the C scale
Tensile Strength, Ultimate	34,000-54,000 psi
Tensile Strength, Yield	23,000-32,000 psi

Chemical Composition of Wrought Iron (percentage by weight)

Iron	99.0-99.8%
Carbon	0.05-0.25%
Manganese	0.01-0.1%
Silicon	0.2% max
Sulfur	0.1% max
Phosphorus	0.2% max

Obviously, wrought iron does not make a particularly hard rifle barrel. Nor is it particularly strong. But it doesn't have to be because typical pressure levels at the breech of a side-lock muzzleloader are under 20,000 psi. Modern in-line muzzleloaders can and do approach 30,000 psi with magnum loads and will require barrels made of stouter stuff than wrought iron. Of particular concern to the barrel maker is wrought iron's variability in tensile strength, both ultimate and yield. There are still quite a few wrought iron barrels in service that were forged in the proverbial days of yore. However, there were also many more wrought iron barrels that are no longer with us because they burst under pressure. Since we are setting minimum *safe* standards for muzzleloader barrels, we would be well advised to take the highest values of tensile strength obtainable with wrought iron (54,000 psi ultimate and 32,000 psi yield) as our minimum acceptable level of strength. And even these values aren't acceptable for in-line muzzleloaders.

It will be important later to remember that wrought iron is full of slag inclusions. Someone with a fancy microscope and more free time than I have ever had counted the number of inclusions in wrought iron and determined that there are, on average, about 250,000 inclusions per square inch… I'll take his word for it. Also note the percentages of sulfur and phosphorus contained in wrought iron. We will be looking at free-machining grades of modern steels for use as muzzleloader barrels, both side-lock and in-line, and these steels are characterized by inclusions of sulfur, phosphorus and even lead. The stringers produced by these impurities give the steel its free-machining qualities by allowing chips to fracture at the boundary between the martensite grains (ferrite grains in the low carbon and/or cold drawn grades of steel) and the inclusions. Since our gold standard for muzzleloader barrels, wrought iron, contains the same type of inclusions, there is no compelling reason not to use the free-machining grades of steel that will provide free cutting and longer tool life.

Minimum Requirements for Centerfire Rifle Barrels

The standard set for centerfire barrels during the last century was ordnance steel. Ordnance steel contained enough carbon to allow the alloy to harden through heat-treatment. It also contained a fair amount of manganese to increase the depth of

hardening. By increasing the depth of hardness, a homogeneous steel is produced that isn't hard on the outside while remaining too soft for the intended application near the center, where it is more difficult for the quenching medium to remove heat quickly enough for martensitic transformation. So, the standard for centerfire barrels is homogeneous steel with the following characteristics:

Mechanical Properties of Ordnance Steel

Hardness, Brinell	275-305
Hardness, Rockwell B	104-107
Hardness, Rockwell C	28-32
Tensile Strength, Ultimate	130,000 psi
Tensile Strength, Yield	110,000 psi

Chemical Composition of Ordnance Steel (percentage by weight)

Iron	98.5-98.1%
Carbon	0.40-0.55%
Manganese	1.00-1.30%
Sulfur	0.05% max
Phosphorus	0.05% max

Because of the pressures produced by centerfire cartridges (up to 65,000 psi), the strength required of the barrel steel has increased tremendously over what is considered adequate for muzzleloaders. Remember that the values presented above for strength are *minimums*. Do not, under any circumstances, use a weaker grade of steel to make a centerfire barrel. Even if you're making a barrel for an old-timer like the .45-70 Government and you plan to use only black powder loads, use a grade of steel that can handle the pressure produced by smokeless powder. The rifle will eventually fall into someone else's hands and, if you use a weaker grade of steel, they may get themselves into some serious trouble with high-pressure smokeless loads. Depending on what type of action that .45-70 barrel is screwed into, they may get themselves into trouble with smokeless loads anyway– but at least it won't be *your* fault. Also, note the amount of carbon present in the steel. This level of carbon is required to harden the steel all the way through without causing embrittlement. Yes, more carbon would make the steel stronger, but it would also make it more likely to fracture. For example, the tensile strength of O-1 tool steel (both ultimate and yield) is nearly twice that of ordnance steel, but a barrel made of O-1 could very well burst when fired because its carbon content of 0.85-1.00% makes it far too brittle for this application. Barrel steel needs to be elastic.

Another difference between the steel used for centerfire barrels and the wrought iron used for muzzleloader barrels is the nearly surgical cleanliness of the alloy. Only trace amounts of sulfur and phosphorus are considered acceptable for centerfire barrels. As previously mentioned, stringers of impurities in the steel make it easier to machine, but they also create potential points of weakness where barrel fractures can begin to form. Those of you who are familiar with the alloys used for modern centerfire barrels will likely have heard that 416R stainless steel barrels can fracture at extremely high or low temperatures. This weakness is due to 416R's increased sulfur content of 0.13%. The suitability of this alloy for centerfire barrels is a valid concern and we will discuss 416R

in more detail later. We will also look at two alternative grades of stainless steel for rifle barrels that do not have a high percentage of sulfur.

Speaking of stainless steels, only the mechanical properties listed above apply to the stainless alloys. The chemical composition of stainless steels is far more complex than what is presented in this section. We will look at the exact chemical composition of suitable stainless steel alloys later.

Hardening of Barrel Steel

There are three ways to make steel hard enough for use as a barrel blank. The first, and most common, method is to heat the steel to its critical temperature and then quench it in oil. This hardening process is then followed by tempering to draw the hardness of the steel to the desired level. The second method is work-hardening. This is done by cold-swaging the steel to a smaller diameter. Cold-swaging is followed by stress relief so that the barrel will remain straight during subsequent machining operations. The final method of hardening barrel blanks is precipitation-hardening. The precipitation-hardening process can only be performed on alloys with the proper chemistry and only one of the steels that we will examine has the correct chemistry for this method.

Quenching from Critical Temperature

Iron, like most other metals, exists as a crystalline solid at the normal ambient temperatures encountered on the surface of our planet. Volcanic lava flows are excluded from the term "normal ambient temperatures", at least in my neighborhood. However, temperatures equivalent to those achieved inside a volcano are very important to the barrel maker because iron takes on a different crystalline structure at significantly elevated temperatures. But iron's shape-changing shenanigans are not bound exclusively to changes in heat. Atoms of carbon that get trapped inside the unit cells of iron crystals will cause them to form yet another geometric shape. To truly understand what turns iron into steel and what makes steel so special, we must understand how a simple change of crystal shape can dramatically affect the mechanical properties of iron.

The critical temperature of a steel alloy (also known as the eutectoid temperature) is the temperature at which the crystalline structure of the iron makes a phase shift from its body-centered cubic structure (ferrite) to its face-centered cubic structure (austenite). There are actually two critical temperatures for steel alloys. At the lower critical temperature, alpha iron (ferrite, aka pure iron) transforms into beta iron. Beta iron is harder than ferrite and has no magnetic properties. At the upper critical temperature, beta iron transforms into gamma iron (austenite). This is the transformation that we want when heat-treating steel alloys, so, from this point on, our discussion of critical temperature will refer to the upper critical only. It's worth noting that the steel will lose its magnetic properties at the lower critical temperature, but it is *not* austenite at this point. This is why the old rule of thumb about holding a magnet near steel to determine when it's ready to be quenched is not the best way to heat-treat modern steel alloys. A temperature-controlled furnace equipped with a thermocouple is much better suited to optimizing the heat-treatment.

The critical temperature of an alloy depends upon the amount of carbon and other alloying elements contained in the steel. For plain carbon steel (no other alloying elements), the critical temperature is 1,333°F at a carbon concentration, measured by

weight, of 0.90%. As the carbon concentration varies, higher or lower, from 0.90% (hypereutectoid or hypoeutectoid steels), the upper critical temperature begins to increase dramatically; however, the lower critical temperature remains 1,333°F at all carbon concentrations when no other alloying elements are present. The critical temperature of pure iron (no carbon) is 1,706°F. As the carbon concentration approaches 2.0%, the critical temperature exceeds 2,000°F. Alloying elements other than carbon, such as manganese and molybdenum, will also change the critical temperature of a steel alloy. This is why 4140 chrome-moly steel has a critical temperature of 1,550°F while the critical temperature of 1040 plain-carbon steel is only 1,480°F. The take home message is this: it is vitally important to have *specific* heat-treating instructions for any steel alloy that you intend to harden and/or temper by heat-treatment.

The reason that the structure of the iron crystal changes at the critical temperature is that this is the transition point at which the individual iron atoms become energetic enough to break the bonds between them. By breaking the bonds that constrained them to a body-centered cubic structure, the atoms become mobile and can rearrange themselves into a new unit cell configuration called face-centered cubic. Individual atoms are also free to move between unit cells within the crystal lattice and change their spatial relationships with other atoms. They can move to a new neighborhood with brand new neighbors. The sudden mobility of the iron atoms that allows the phase transition at the critical temperature is not terribly important to the metallurgist. What *is* important is the fact that when iron atoms become mobile enough to rearrange themselves, they also allow the atoms of other elements to mingle amongst them and this phenomenon opens up a whole new world of possibilities.

Carbon exists in the form of cementite (iron carbide) in steel that has been slowly cooled (annealed) from the critical temperature. The cementite is excluded from the iron lattice when the phase transition is made slowly from austenite at critical temperature to ferrite at lower energy levels. The resulting annealed steel is an intricate mixture of intertwined layers of ferrite and cementite crystals. This layered structure is called pearlite and it is quite soft because all free iron (iron not tied up in iron carbide molecules) is in the form of ferrite. So it should come as no surprise that pearlitic steel is mechanically very similar to pure iron. When the time comes to harden the steel, the pearlite is again heated to critical temperature and its ferrite component will once again transform into austenite. When this occurs, the carbon atoms present in the cementite will begin to migrate into the austenite lattice. However, the fate of the carbon atoms will be quite different this time. Since the purpose of this heating is to harden the steel, it will be *rapidly* cooled from the critical temperature.

Rapid cooling does not allow the carbon atoms enough time to escape the austenite lattice when it tries to transform back into ferrite. As a result, some of the unit cells of the iron lattice have a carbon atom jammed awkwardly between the iron atoms in their structure. In effect, trapping carbon in the iron lattice is just like trying to close a suitcase that is stuffed with twice as many clothes as it was designed to carry– you can't quite get the lid closed. By overfilling the iron unit cell, the interstitial carbon atoms cause the iron to make yet another phase transition to body-centered tetragonal (martensite).

Martensite is the stuff we are looking for in heat-treatable steels. The inability of the martensite unit cells to assume the same compact size as ferrite causes the cells that

border martensite to become slightly displaced. This displacement (dislocation) is what is commonly referred to as an intentional crystal defect. Crystal defects cause misalignment of neighboring unit cells. The misalignment, in turn, creates snags (pinning points) in the iron lattice that make it much more difficult for the unit cells to be displaced further. We recognize this increased resistance to displacement as an increase in hardness and strength. In fact, the hardness of a substance is determined by controlled displacement of a portion of the material followed by a subsequent measurement of the amount of displacement produced by a known force applied to a known area. In other words, hardness increases when the force required to displace a portion of the lattice increases. The measured hardness of an alloy that has been quenched can be predicted by its carbon content. Dislocation density and hardness increase in direct proportion to the number of interstitial carbon atoms that were trapped within the iron lattice during the quench. However, increased hardness is not all beer and skittles. It also causes embrittlement that will cause fracturing instead of flexing under heavy loads.

The quenching process is not at all subtle. There is no finesse involved in dunking a red-hot piece of steel into a vat of oil. Quenching causes *all* of the available carbon to be trapped inside the iron lattice, making the alloy as hard as it can possibly be. It also causes internal stresses at the maximum attainable levels. Quenching austenite to form martensite is basically like placing millions of compressed, atom-sized springs in the lattice. And compressed springs apply force to whatever it is that's compressing them. Un-tempered martensite is very brittle and prone to fracture along grain boundaries. Because we need our barrel blanks to be tough and flexible instead of brittle and rigid, the state of maximum hardness and internal strain will not suffice. Our barrel blanks need to be tempered in order to draw the hardness and brittleness of the steel down to a level that is more appropriate for the application.

When hardened steel is tempered, a portion of the interstitial carbon atoms that were trapped in the martensite lattice during the quenching process are released from the lattice and precipitate as cementite. At relatively low tempering temperatures, little carbon is released. The steel will remain nearly as hard as it was when first removed from the quenching medium, but the martensite grain structure will be stabilized and much of the quench-induced stress will be relieved. As the tempering temperature increases, a larger percentage of carbon will precipitate out of the martensite lattice. This causes the steel to lose a considerable portion of the strength and hardness it attained during the quench, but significant gains are made in the steel's toughness and elasticity.

The desired temperature for the tempering process will vary according to the alloy being heat-treated and the intended application of the finished product. Lower tempering temperatures produce good cutting edges while higher temperatures produce good chisels and hammers that will have to survive severe impact. Regardless of the alloy of steel being used or the desired level of hardness and strength, the tempering temperature must be less than the critical temperature for the alloy. Martensite will always transform back into austenite at the critical temperature and that transformation will undo all heat-treatments that came before it. More importantly to the barrel maker, once the required physical characteristics of a barrel blank have been achieved by tempering, the steel *must* be kept at a temperature *at least* 25°F lower than the tempering temperature during all subsequent operations (soldering, brazing, welding, etc.). If, at any time, the tempering temperature is reached or exceeded, the portion of the barrel that was overheated will

become too soft for the application and the barrel will have to be scrapped or heat-treated again from the critical temperature. And the bore, with its butter-smooth lands and grooves, is not likely to fair well when heated to critical temperature.

Work-Hardening

Steel, and most other metals, can also be work-hardened. Believe it or not, the work-hardening effect operates on the same principle as the dislocations caused when austenite transforms into martensite. But instead of using interstitial carbon atoms to cause dislocations by changing the dimensions of a portion of the iron unit cells, we are physically displacing unit cells from their original positions to achieve the same effect. Heat-treatments will not work on steel alloys that contain less than 0.30% carbon. These alloys can't form enough martensite crystals to harden during a quench from critical temperature, so work-hardening is the only option to harden these steels. But even if the steel contains enough carbon to be heat-treated and tempered, it can be work-hardened by machining operations such as cold-drawing, button-rifling and hammer-forging.

Steel exhibits one of two kinds of deformation when stressed. If the applied force does not exceed the yield strength of the alloy, the iron lattice will give a bit and then spring back into its original shape when the force is removed. This is called elastic deformation. Elastic deformation will not harden the alloy. However, if the applied force does exceed the yield strength of the alloy, the displacement of the lattice will be permanent. This is called plastic deformation. Plastic deformation does harden the alloy by creating the same kind of crystal defects produced by martensitic transformation. And, just like martensitic transformation, the measured hardness depends upon the dislocation density within the crystal lattice. The more dislocations produced, the harder the steel becomes.

Unlike heat-treatment, which is a one-shot deal, the effects of work-hardening are cumulative. If the crystal lattice is repeatedly displaced by forces that exceed the yield strength, the lattice will continue to accumulate dislocations. But the process is not without its own system of checks and balances. An increasing number of dislocations doesn't just increase the hardness of the alloy, it also increases the yield strength. Obviously, the work-hardening process can't continue indefinitely under these conditions. Eventually, either the yield strength of the steel will exceed the magnitude of the forces being applied to it, or the steel will fracture because it has become too hard and brittle for further plastic deformation.

Stresses are induced in work-hardened steel just as they are in quenched steel. However, work-hardened steel is stress-relieved instead of being tempered. So what's the difference between stress-relief and tempering? Not much, really. The only real difference is the fact that the exact temperature used for stress-relief isn't nearly as critical as it is with tempering. We're not releasing a specific amount of carbon from the lattice here. We're just allowing the lattice to relax a bit so that it will not alter shape or dimensions when we don't want it to, such as during the barrel profiling operation or when firing a string of shots through the finished rifle at the range. The temperature used to stress-relieve steel depends upon whether or not the increase in hardness and strength is beneficial to the end use of the steel. High temperatures will remove the majority of stress and work-hardening while lower temperatures will retain some of the hardness and relieve only peak stresses in the final product.

Precipitation-Hardening

Precipitation-hardening is a process used to harden some stainless steels as well as other alloys (such as aluminum) that can't be hardened by conventional heat-treatments. As with conventional heat-treatment and work-hardening, precipitation-hardening depends upon the production of crystal defects (dislocations) to increase the strength and hardness of the alloy. Precipitation-hardening depends upon the nucleation (precipitation) of impurities within the iron lattice to cause the required unit cell displacement. Carbon content of precipitation-hardening stainless steels is intentionally kept very low to reduce embrittlement and improve toughness. Precipitation-hardening stainless steels can be conventionally heat-treated prior to the precipitation-hardening process. We will be looking at a martensitic grade of stainless steel, which will indeed form martensite during the quench. The martensite start temperature of this alloy is 270°F and the martensite finish temperature is 90°F, so a *complete* quench to room temperature is very important. The initial heat-treatment is followed by precipitation-hardening.

Precipitation-hardening takes place at temperatures that are high enough to increase the solubility of the impurities within the iron lattice. The temperatures used for stainless steels fall into the range of 890-1,150°F with the lower temperatures producing greater hardness and strength in the finished alloy. Note that the alloy remains below critical temperature for this process. Once the impurities are in solid solution and mobile within the alloy, they will begin to nucleate and grow. In martensitic stainless steels, the scattered martensite structures provide numerous locations for nucleation to begin. This is why the conventional heat-treatment prior to precipitation-hardening is so important. Once the impurities have nucleated, the alloy is held at temperature for a period of several hours to allow the newly formed particles to grow. This growth phase is called aging.

The size of the impurity particles within the alloy is very important and, as was the case with work-hardening, the effects of the aging treatment are cumulative. If the aging process is ended prematurely, the particles will be too small to achieve the desired effect. New dislocations, caused by a force acting against the alloy, can cut through particles of insufficient size. However, aging the alloy for too long is also detrimental. If the particles are allowed to grow too large, dislocations can bow around their edges and continue through the material. In either case (too small or too large), the impurities within the iron lattice will not harden and strengthen the alloy because they can't stop the propagation of new dislocations. The aging process must be done at just the right temperature for just the right amount of time to achieve the desired effect. Particles of the proper size for the intended application are said to attract new dislocations to the strain fields they create and stop the dislocations dead in their tracks. By doing so, they will increase the hardness and strength of the alloy.

Precipitation-hardening requires no additional tempering step. In fact, aging the alloy at temperature basically *is* a tempering operation that will stabilize the iron lattice with the bonus that it also causes the nucleation and growth of particles that will increase the strength of the steel. As with all other steels, machining operations can induce stresses within precipitation-hardening alloys that will require a stress-relief treatment to alleviate. A precipitation-hardening stainless steel should be kept below the aging temperature during all subsequent operations (soldering, brazing, welding, etc.) and the

time held at elevated temperatures should be kept to a minimum. Remember that the impurity particles will grow at high temperatures and particles that become too large can't do their job. But since it takes hours for the particles to grow, normal gunsmithing operations will have no harmful effect as long as the work is performed quickly and efficiently.

Barrel Steel Alloys

In this section, we will examine the physical properties, advantages and disadvantages of five types of modern steel alloys that can be used to make rifle barrels. Two of these alloy types are suitable only for muzzleloader barrels (and one of these only for *sidelock* muzzleloaders), while the other three meet the requirements for all applications up to and including magnum centerfire rifles. To the best of my knowledge, each of these alloys is currently being used for rifle barrels by at least one major firearms/barrel manufacturer and untold numbers of custom barrel makers. Each alloy has its own unique characteristics in terms of strength, toughness, wear resistance and machinability. It is the task of each individual barrel maker to decide which alloy will best suit his needs.

12L14 Resulfurized and Rephosphorized Steel

12L14 is a low-carbon grade of free-machining steel that is used by several different barrel makers for muzzleloading use. As a low-carbon grade, 12L14 can't be hardened by heat-treatment. The only way to increase the strength of this alloy is through work-hardening. We will be looking at the physical properties of 12L14 in both the hot-rolled and cold-rolled (work-hardened) condition. Barrels have been made from raw bars produced by both methods.

12L14, Cold Drawn

Mechanical Properties

Hardness, Brinell	163
Hardness, Rockwell B	84
Hardness, Rockwell C	Can't be measured on the C scale
Tensile Strength, Ultimate	78,300 psi
Tensile Strength, Yield	60,200 psi
Machinability	160% (based on AISI 1212 @ 100%)

12L14, Hot Rolled

Mechanical Properties

Hardness, Brinell	121
Hardness, Rockwell B	68
Hardness, Rockwell C	Can't be measured on the C scale
Tensile Strength, Ultimate	57,300 psi
Tensile Strength, Yield	34,100 psi
Machinability	170% (based on AISI 1212 @ 100%)

Chemical Composition

Iron	97.9-98.7%
Carbon	less than 0.15%
Manganese	0.85-1.15%
Sulfur	0.26-0.35%
Phosphorus	0.04-0.09%
Lead	0.15-0.35%

This grade of steel contains significant percentages of sulfur, phosphorus and lead (the "L" in 12L14 means "this alloy contains lead") to provide unrivaled free-machining qualities. Look at the machinability rating! This is the closest thing to a hot-knife-through-butter effect that you can get when machining steel. The machinability rating is so high because sulfur, phosphorus and lead all form inclusions between the steel grains on a microscopic scale that provide fracture points where chips can break freely away from a cutting tool during machining operations. Ease of machining is the property that makes the alloy so attractive to producers of low-priced muzzleloaders. Unfortunately, the chemistry that makes 12L14 so easy to machine also makes it barely suitable for mild loads in sidelock muzzleloaders. Sulfur and phosphorus have the same effect on all other steel alloys that they have on 12L14, so remember the following discussion for later application to some of the other free-machining alloys we will discuss.

Sulfur inclusions make a steel alloy hot-short, which means that sulfur increases the likelihood that seams will open up in the steel at forging temperatures (1,800°F and higher). There is also a rumor out there, specifically applicable to rifle barrels, which states that the sulfur inclusions can sometimes burn away in the presence of hot propellant gases. Once the inclusions are burned away, so the story goes, the space they once occupied is now vacant, leaving a microscopic opening for propellant gases to begin forcing their way into the wall of the barrel. Repeated firings are said to cause the crack to widen incrementally with each shot, eventually leading to a fracture of the barrel wall. There may be some truth in this hypothesis. I honestly don't know. But in the case of muzzleloader barrels, the presence of microscopic sulfur inclusions in the steel does not concern me (remember the inclusions in wrought iron?). Black powder does burn hot, but the pressures are low and no one on the face of the earth can load and fire a muzzleloader fast enough to heat the barrel to the temperatures required to make the steel hot-short. However, centerfires can be, and often are, shot rapidly enough to heat the steel into the danger zone and the effect of sulfur should not be ignored in centerfire barrels. We will discuss this topic more thoroughly when we examine 416R stainless steel.

Sulfur is not the only free-machining additive contained in 12L14. It also contains phosphorus and lead, each of which has a more troublesome effect on muzzleloader barrels than sulfur. Phosphorus causes steel to become cold-short, which means that it is brittle at low temperatures. All rifle barrels are cold for the first shot and muzzleloader barrels are cold for every shot, so the presence of phosphorus doesn't exactly give me a warm, fuzzy feeling. However, the phosphorus content of 12L14 is not excessively high. It is recommended that steel alloys contain less than 0.06% phosphorus for best performance, and 12L14 contains a *maximum* of 0.09% phosphorus, so it's not too far out of the ballpark. The same can't be said for the lead content of 12L14. Lead makes steel softer and weaker at all temperatures and under all circumstances. Steel should contain

zero lead for best performance. When you add it all up– sulfur *plus* phosphorus *plus* lead– 12L14 is certainly not the ideal steel alloy for a rifle barrel. But again, this alloy has been, and continues to be, used for muzzleloader barrels so I won't tell you that you shouldn't use it. But I will advise you to keep maximum loads fairly light.

Of the two available treatments for 12L14, the cold-rolled version is eminently more suitable for use as a rifle barrel. It is both harder and stronger than its hot-rolled kin. The hot-rolled version does measure up to the minimum standard for muzzleloader barrels that was set by wrought iron centuries ago, but that's not the whole story. Some manufacturers of cheap muzzleloaders have used 12L14 barrels from Spain that are hot-rolled over a mandrel so that reaming and rifling are the only steps left to finish the barrel blank. The grain structure of these barrels tends to parallel the bore because the steel is austenitic when rolled longitudinally. This results in good linear strength, but very poor hoop strength. As a result, these barrels tend to swell and burst with loads that should be completely safe in a muzzleloader. For those of you who know a bit about European standards for black powder barrels– yes, these barrels are usually proof-fired. But they are proof-fired with proof loads that generate reported peak pressures less than 10,000 psi. This is hardly a suitable proof-firing for a barrel that will have to handle hunting loads that may exceed 30,000 psi. Because of the hoop strength issues, I wouldn't make a barrel from hot-rolled 12L14 for love nor money.

Despite its literal weaknesses, cold-drawn 12L14 can be used to build a muzzleloader barrel for use in a sidelock rifle. In fact, I own a rifle with a 12L14 barrel that I purchased before I began making my own barrels. This barrel has shown no signs of stress or strain so far. I must say, however, that I refuse to push it to the manufacturer's recommended maximum loading. With a steel alloy this weak, I prefer to keep pressures well under 15,000 psi. Because of my own misgivings about the strength of this steel and the pressures that I feel are reasonably safe in these barrels, I strongly recommend that a different alloy be used for in-line muzzleloaders that can easily generate pressures between 25,000 and 30,000 psi with modern, magnum loadings. Besides, there are other free-machining alloys that are considerably harder and stronger than this one, so why pick the runt of the litter for *any* muzzleloader barrel? *All* of the other alloys examined in this chapter are stronger, safer and more suitable for rifle barrels than 12L14.

1144 & 1137 Resulfurized Steel

1144 and 1137 are medium-carbon grades of free-machining steel. 1137 is widely used by major manufacturers of muzzleloaders while 1144 is used mostly by custom muzzleloader barrel makers (including yours truly). As medium-carbon steels, these two grades can be hardened by work-hardening or heat-treatment. We will be looking at both alloys in the cold-rolled and heat-treated conditions. Either hardening treatment with either alloy will produce a barrel blank suitable for all muzzleloading applications, including magnum, in-line rifles. Despite the tensile strength figures for these alloys, *do not* use an 11-series steel to make a centerfire barrel. Centerfire rifles (even single shots) are capable of firing a large number of copper-jacketed bullets at high velocities and pressures in a short period of time and require barrels that are more resistant to wear, abrasion and high temperatures than these two alloys. Leave the resulfurized steels to the front-loading rifles that are capable of firing no more than three or four cotton-patched round balls or soft lead conical bullets per minute.

Niagara LaSalle Stressproof® 1144, Cold Drawn, Stress-Relieved

Mechanical Properties

Hardness, Brinell	212
Hardness, Rockwell B	94
Hardness, Rockwell C	16
Tensile Strength, Ultimate	115,000 psi
Tensile Strength, Yield	100,000 psi
Machinability	83% (based on AISI 1212 @ 100%)

Chemical Composition

Iron	97.5-98.0%
Carbon	0.40-0.48%
Manganese	1.35-1.65%
Silicon	0.15-0.35%
Sulfur	0.24-0.33%
Phosphorus	0.04% max

1144, Cold Drawn, Low Temperature Stress-Relieved

Mechanical Properties

Hardness, Brinell	212
Hardness, Rockwell B	94
Hardness, Rockwell C	16
Tensile Strength, Ultimate	105,000 psi
Tensile Strength, Yield	95,000 psi
Machinability	83% (based on AISI 1212 @ 100%)

1144, Oil Quenched (1,550°F), Tempered (1,000°F)

Mechanical Properties

Hardness, Brinell	212
Hardness, Rockwell B	94
Hardness, Rockwell C	16
Tensile Strength, Ultimate	105,000 psi
Tensile Strength, Yield	68,200 psi
Machinability	79% (based on AISI 1212 @ 100%)

Chemical Composition

Iron	97.5-98.0%
Carbon	0.40-0.48%
Manganese	1.35-1.65%
Sulfur	0.24-0.33%
Phosphorus	0.04% max

1137, Cold Drawn, Low Temperature Stress-Relieved

Mechanical Properties

Hardness, Brinell	187
Hardness, Rockwell B	90
Hardness, Rockwell C	10
Tensile Strength, Ultimate	95,000 psi
Tensile Strength, Yield	84,800 psi
Machinability	76% (based on AISI 1212 @ 100%)

1137, Water Quenched (1,550°F), Tempered (1,000°F)

Mechanical Properties

Hardness, Brinell	229
Hardness, Rockwell B	96
Hardness, Rockwell C	19
Tensile Strength, Ultimate	110,000 psi
Tensile Strength, Yield	71,100 psi
Machinability	79% (based on AISI 1212 @ 100%)

Chemical Composition

Iron	97.8-98.3%
Carbon	0.32-0.39%
Manganese	1.35-1.65%
Sulfur	0.08-0.13%
Phosphorus	0.04% max

The 11-series free-machining steels are far more suitable for heavy hunting loads in muzzleloading rifles than 12L14. The tensile strength and hardness of these grades far exceeds the standard set by wrought iron, which makes them safe for use as magnum, in-line muzzleloader barrels. These alloys are not as easy on cutting tools as 12L14, but I can attest from personal experience that they cut beautifully with a velvet smooth finish.

The choice between 1144 and 1137 is an interesting one that caused me to toss and turn on countless sleepless nights before I finally dug up enough information to make what I consider to be an informed decision. 1144 contains more carbon, but it also contains more sulfur. The increased carbon content makes 1144 a bit stronger and tougher than 1137, while the higher sulfur content makes it slightly more likely to fracture under extreme stress. This is where the individual barrel maker has to make a judgment call based upon the muzzleloading standard– wrought iron. Remember the 250,000 inclusions per square inch in wrought iron? Those inclusions contain both sulfur and phosphorus and these elements have the same effect on wrought iron that they have on modern steel alloys. They make it more likely to fracture. Well-made wrought iron barrels did not fracture because sidelock muzzleloaders do not produce extreme stress. Nor can they be loaded and fired fast enough to heat the barrel to the temperatures at which sulfur does, indeed, cause serious problems by weakening the bonds between individual grains within the steel. Because of the relatively low pressures and temperatures that a muzzleloader barrel must endure (as compared to centerfire barrels), the yield strength of the alloy is far more important to me than the sulfur content.

If you compare the yield strength of the 11-series hardening treatments listed above, you'll see that cold-drawn 1144 has the highest yield strength. Yield strength tells us more about how well a barrel will contain high pressures than ultimate tensile strength, so I choose 1144 for my muzzleloader barrels. Using steel with a yield strength that is three times higher than the yield strength of wrought iron allows me to sleep very soundly. However, if you plan to hunt in *extremely* cold weather, you may want to consider using 1137 because of its lower sulfur content. Medium-carbon steels are not quite as prone to reduced ductility in cold weather as free-machining, martensitic stainless steels (which we'll discuss shortly) and should exhibit none of the problems associated with 416R stainless steel under these conditions, especially at muzzleloader pressures, but it is something to consider when choosing a barrel alloy. The yield strength of all steel alloys decreases from room-temperature values as temperature decreases, whether the alloy in question contains sulfur or not. So I honestly do not know for sure whether higher sulfur content or lower starting (from room-temperature) yield strength would be more detrimental to the safety of the barrel during bitterly cold weather. But the yield strength of 1144 exceeds that of 1137 by enough of a margin to get my vote for safest 11-series alloy. I have tried to find the ductile-brittle transition temperature (DBTT) graphs for these two alloys to eliminate the guesswork, but I haven't been able to find them yet. For the record, I have fired *proof loads* in 1144 barrels at temperatures well below freezing (as low as 10°F, never below zero) with no problems whatsoever. No matter which alloy you choose, I really don't think you can go wrong with either 1144 or 1137 for muzzleloading applications in any weather conditions. Either alloy with either hardening treatment is a stronger, safer choice than wrought iron or 12L14.

One last issue that can't be ignored if I'm going to recommend cold-rolled 1144 steel for rifle barrel use is the potential for laps and seams in the barrel blank. A lot of folks have made a lot of noise over the seams produced during the cold-swaging method of working steel. As you would expect, the American Iron and Steel Institute (AISI) is also a bit concerned about this type of manufacturing defect. As a result of this concern, AISI has set standards for the maximum allowable seam depth in cold-rolled 1144 bars. The maximum allowable seam depth is .015" for bars up to 5/8" in diameter. For larger bars, seam depth is allowed to increase an additional .0015" for every additional $^{1}/_{16}$" added to the diameter of the bar. This means that for a standard 1.25" barrel blank, the maximum allowable seam depth is .03". In other words, if you machine $^{1}/_{32}$" (.03125") from the radius of the barrel during the profiling operation, *all seams will be completely removed from the finished barrel.* If you choose Niagara LaSalle's patented Stressproof 1144, the tolerance for seam depth is even lower– by 33%. There is no danger that a seam will extend all the way into the bore. Just think about this for a moment. We're talking about cold-forming *steel*, not salt-water taffy. The stuff is only going to give so much and it's certainly not going to fold and twist itself into a seam-ridden knot during a simple swaging operation. If that could happen, the cold-swaging method of manufacturing steel would have been abandoned for all applications long ago. Just ask any knife maker who produces Damascus blades how easy it is to create deep folds in steel. I guarantee that he will tell you it requires far more violence than the comparatively gentle squeeze produced by a cold-swaging operation. The final assurance to cover the "what-ifs", no matter how unlikely those ifs may be, is the proof-firing. If, somehow, a seam does manage to worm its way deep into the barrel blank during the cold-forming operation, the barrel will burst

during proof-firing before it's made into a finished rifle. I have never had a cold-drawn 1144 barrel fail the proof-firing test and that fact, I think, speaks for itself.

4140 Chromium-Molybdenum Steel

4140 is a medium-carbon grade of chrome-moly steel. 4140 is universally used by major manufacturers of centerfire rifles and barrels. As a medium-carbon steel, 4140 responds well to heat-treatment, producing a tough, homogeneous steel. This is *the* gold standard of barrel steel for centerfire rifles. 4140 is suitable for any and all rifle barrel applications up to and including machine guns capable of firing upwards of a thousand rounds per minute.

4140, Oil Quenched (1,550°F), Tempered (1,000°F)

Mechanical Properties

Hardness, Brinell	285
Hardness, Rockwell B	105
Hardness, Rockwell C	30
Tensile Strength, Ultimate	140,000 psi
Tensile Strength, Yield	116,000 psi
Machinability	65% (based on AISI 1212 @ 100%)

Chemical Composition

Iron	96.8-97.8%
Carbon	0.38-0.43%
Manganese	0.75-1.00%
Chromium	0.80-1.10%
Molybdenum	0.15-0.25%
Silicon	0.15-0.30%
Sulfur	0.04% max
Phosphorus	0.04% max

4140 was developed for truck axles and other heavy-duty applications that require both strength and toughness. Of course, strength and toughness are required in rifle barrels as well, so 4140 is an excellent choice for this application. When properly heat-treated, this alloy exhibits the ideal properties of hardness, strength and toughness for centerfire barrels. 4140 is not a free-machining steel so cutting speeds must not be excessive if good tool life is expected. Despite its machinability rating of only 65%, chrome-moly steel cuts very nicely and I have always gotten a smoother machined finish with it than I ever have with plain old 1018.

The chromium in chrome-moly steel has an interesting, and very beneficial, effect on the alloy. When added to steel in small amounts, chromium will increase the hardness of the alloy *without* reducing the ductility. This means that the tensile strength will increase without sacrificing the ability to withstand abrasion and impact. This is about the closest thing to a free lunch you will ever see with steel alloys. It is far more common for an alloying element to cause one parameter to go down as another goes up, leaving the end-user to decide for himself which physical characteristic is more important.

Chromium also adds to the corrosion resistance of the alloy, although this effect is not particularly significant at such low concentrations of chromium.

The molybdenum content also adds to the toughness of this alloy. However, the most significant contribution of the molybdenum is its ability to broaden the range of tempering temperatures that will produce a given set of physical properties. In other words, if the tempering furnace gets a bit too hot or stays a bit too cold, the finished product will be essentially the same as if the perfect tempering temperature was nailed exactly. This gives the steel manufacturer some breathing room. It also gives the barrel maker piece of mind because he knows that his barrel blanks will be suitable even if the heat-treatment wasn't quite optimal.

Silicon is added to chrome-moly steel, as well as many other steel alloys, because it has the ability to keep molten steel from out-gassing during the pour. The formation of froth and bubbles as steel transitions from a liquid to a solid will cause voids to form in the finished bar and these voids would, in turn, cause weak spots in the barrel that could cause a rupture or fracture when the rifle is fired.

4140 is suitable for all centerfire cartridges in all weather conditions. This alloy will remain ductile at temperatures far lower than any sane hunter would venture out into. At the other end of the spectrum, 4140 will retain enough of its tensile strength to contain the pressure of centerfire cartridges at temperatures up to, literally, red-hot. In fact, 4140 will handle this sort of abuse better than any other barrel alloy that I know of. That's why all military barrels are made with it. However, chrome-moly steel is not indestructible and it shouldn't be treated as if it is. I have seen micrograph images of a badly abused and ruptured 4140 military rifle barrel that clearly showed upper bainite formations in the microstructure. Bainite is the microstructure of iron that forms when steel cools from high temperatures (750-1,020°F for upper bainite) too quickly to form pearlite. Bainite is characterized by large inclusions of brittle cementite crystals and it is definitely not a good thing to have lurking in the walls of a rifle barrel. That should give you something to think about during your next prolonged rapid-fire session.

I have seen some references to using 41L40 to make rifle barrels. I have found no specs for this alloy nor have I found a steel manufacturer who produces it (although, I must admit, I haven't looked very hard). I'm only mentioning it because of the references I've seen and the possibility that someone may manage to find it and use it to make a rifle barrel. As far as suitability is concerned, we have already discussed the detrimental effect that lead has on 12L14 steel for use as muzzleloader barrel material. I can't imagine that the addition of lead would be a good idea in a *centerfire* barrel. Besides, as I mentioned above, 4140 cuts beautifully, albeit at slower cutting speeds than free-machining steel. I can't imagine that saving a few minutes during the machining process would be worth reducing the strength and toughness of the best centerfire barrel steel available. But, each barrel maker will have to decide for himself whether or not to include 41L40 on the list of candidates for his own rifle barrels.

There's really not much more to say about 4140. It has passed every test in every type of firearm that is currently available under every imaginable condition. No matter what ballistic question you ask this alloy, it will have the answer. As John "Pondoro" Taylor said of the 9.3 × 62 Mauser cartridge, "Everybody found it so generally satisfactory that there wasn't anything to start a discussion." And so it is with 4140 chrome-moly steel rifle barrels; they simply work.

416R, 416 & 410 Martensitic Stainless Steel

416R is a free-machining grade of martensitic stainless steel that was developed specifically for use as rifle barrel steel. As a martensitic stainless steel, 416R can be hardened by heat-treatment. This is, by far, the most common type of stainless alloy used for making rifle barrels by major manufacturers and custom barrel makers alike. 416R is suitable for all rifle barrel applications, except sustained rapid-fire. Common 416 is presented for comparison with 416R and is suitable for muzzleloader barrels. Despite the fact that 416 and 416R are quite similar in chemical composition and mechanical properties, *do not* use regular 416 for centerfire barrels. There is a very definite reason why a special grade of 416 with *precise* metallurgy was developed for that task. 410 is a more difficult alloy to machine, but is used by some barrel makers because of the potential problems associated with 416R under certain conditions. If you're willing to machine it, 410 is also suitable for all rifle barrel applications and is the safest of the 400-series alloys.

Crucible 416R, Oil Quenched (1,825°F), Tempered (1,000°F)

Mechanical Properties

Hardness, Brinell	285
Hardness, Rockwell B	105
Hardness, Rockwell C	30
Tensile Strength, Ultimate	140,000
Tensile Strength, Yield	120,000
Machinability	85% (based on AISI 1212 @ 100%)

Chemical Composition

Iron	86.05%
Carbon	0.12%
Manganese	0.40%
Chromium	12.5%
Molybdenum	0.40%
Silicon	0.40%
Sulfur	0.13%
Phosphorus	0.03%

416, Oil Quenched (1,750-1,850°F), Tempered (1,000°F)

Mechanical Properties

Hardness, Brinell	260
Hardness, Rockwell B	103
Hardness, Rockwell C	26
Tensile Strength, Ultimate	135,000 (@ room temperature)
Tensile Strength, Yield	110,000 (@ room temperature)
Machinability	90% (based on AISI 1212 @ 100%)

Chemical Composition

Iron	86.0%
Carbon	0.15% max
Manganese	1.25% max
Chromium	12.0-14.0%
Molybdenum	0.60% max
Silicon	1.00% max
Sulfur	0.15% max
Phosphorus	0.06% max

410, Oil Quenched (1,750-1,850°F), Tempered (1,000°F)

Mechanical Properties

Hardness, Brinell	331
Hardness, Rockwell B	109
Hardness, Rockwell C	35
Tensile Strength, Ultimate	154,200
Tensile Strength, Yield	128,000
Machinability	55% (based on AISI 1212 @ 100%)

Chemical Composition

Iron	86.0%
Carbon	0.15% max
Manganese	1.00% max
Chromium	11.5-14.5%
Nickel	0.50% max
Silicon	1.00% max
Sulfur	0.03% max
Phosphorus	0.04% max

The martensitic alloys are not truly stainless steel– they can rust. They can also be heat-treated just like carbon steel and this is the reason why these grades are used for rifle barrels instead of the austenitic stainless grades, most of which offer much better corrosion resistance. One of the biggest problems with stainless steel, from a barrel maker's point of view, is the difficulty of machining the stuff. Even if the hardness and other physical properties are conducive to easy machining, stainless steel has the annoying tendency to gall and build up on the cutting edge of the tool. This buildup not only dulls the cutting edge, it also coats it with a thin layer of material that has the same hardness and chemical composition as the workpiece. A cutting tool must be harder than the material being cut, so this is not a good situation and it only gets worse if not corrected frequently during the machining operation. As you can see from the machinability ratings of 416 and 416R, the addition of sulfur to the alloy alleviates this problem, but causes other more serious problems that we will discuss shortly. If you use 410 to make rifle barrels, you will need to ask your deep-hole drill manufacturer which cutting fluid he recommends for this alloy. *Don't* ask a cutting oil manufacturer which fluid is best or you will be led astray. Stick with the advice of the guys who make and use the tools. Trust me on this one. I have $400 worth of useless, oil manufacturer-

recommended cutting oil sitting in my shop that reminds me of this expensive lesson on a daily basis. You will also need to use a very good cutting oil during the rifling operation and inspect the hook cutter frequently for build-up on the cutting edge.

The problem with the free-machining grades of stainless steel for use as rifle barrels is the sulfur content that makes them cut easily. The sulfur gremlin can rear its ugly head in a stainless steel, centerfire barrel at both high and low temperatures. Problems surface at high temperatures when a firearm with a stainless steel barrel is shot in rapid-fire mode. Remember the tendency of sulfur to make a steel hot-short at forging temperatures, resulting in an increased likelihood of seam formation? Rapid-firing can and does elevate the temperature of the barrel to very near this level. One manufacturer of 416R pistol barrels has examined barrels that burst during rapid-fire sessions, some of which exhibited temper colors indicating that the barrels had been shot until the temperature reached *at least* 1,300°F. Heating a barrel made of *any* steel alloy to this temperature would be detrimental because this is higher than the 1,000°F temper (give or take a few degrees, depending on the alloy) that produces the correct hardness and ductility for the application. But when you add sulfur and its hot-short problems to the mix, the result is an unsafe situation with a very high probability of catastrophic barrel failure. Crucible (the manufacturer who makes 416R) provides the tensile strength of 416R at elevated temperatures, and the tensile strength at 1,300°F is only *14,000 psi*! That is not a typographical error missed by the editor; it's really fourteen-thousand.

Sulfur is also guilty of causing 416R's low temperature problems and, again, it is due to an increased likelihood of fracture. Martensitic stainless alloys, including 410, are prone to severe embrittlement at sub-zero temperatures, far more so than is the case with chrome-moly steel. Because of the intentional weakening of the bonds at grain boundaries with sulfur inclusions in 416R and 416, these alloys are more likely to fracture at temperatures below the DBTT than other stainless alloys. Note that the tensile strength figures for common 416 are specified as being "at room temperature". The tensile strength of *all* steel alloys will change with temperature, but this is the only alloy I've researched for use as rifle barrel steel that carries this disclaimer on the manufacturer's specifications. It reads a lot like a warning that says "this stuff *will* crack when it's cold". Implied disclaimers like that make me nervous, but Crucible states, in writing, that their 416R grade is safe for use as rifle barrel steel down to -40°F. However, they do not specify a minimum barrel wall thickness or maximum peak pressure that will be safe at this temperature. Considering the fact that there are untold thousands of 416R barrels out there being used during cold weather, I would feel safe making a centerfire barrel out of this stuff. But I certainly wouldn't try to machine the barrel down to an ultra-light profile. Heavier is definitely better with 416R.

As for the suitability of 416R and 416 for muzzleloader barrels, I consider both quite sufficient. As mentioned previously, there is no way to fire a muzzleloader fast enough to create hot-short problems. And considering the fact that countless numbers of centerfire barrels made of 416R have been fired in cold weather without bursting, it seems a bit silly to think that muzzleloader pressures might cause one to fail under the same conditions. But again, the final choice of barrel steel is yours.

As mentioned briefly above, 410 will also become brittle in very cold conditions. However, since it does not have the sulfur inclusions of its free-machining siblings, it will be less likely to fracture. It will also be less likely to fail under conditions of extreme

heat. But you would be well advised to avoid all stainless alloys on a firearm that will be subjected to rapid-fire. Stick with 4140 for the really tough jobs. In terms of mechanical properties, 410 is, hands-down, the best of the 400-series stainless steel alloys for centerfire rifle barrels. But you need to remember that another important characteristic for rifle barrel steel is its ability to machine fairly easily with a butter-smooth finish inside of the bore. 410 is definitely not the leader in this category. Once again, the barrel maker is left to make a tough decision about which characteristic of a steel alloy is most important...

630 (17-4) Precipitation-Hardening Stainless Steel

630 (aka 17Cr-4Ni) is a martensitic, precipitation-hardening stainless steel alloy. It is hardened by conventional heat-treatment (quenching from critical temperature). In addition to this initial heat-treatment, this alloy can also be precipitation-hardened at different temperatures for different lengths of time to fine tune the physical properties of the finished alloy. With the correct aging treatment, 630 is suitable for all rifle barrel applications. As far as I know, only one major manufacturer has reportedly made *barrels* from 630. But several different manufacturers employ this alloy to make cylinders for powerful revolvers that fire very heavy bullets. We will be looking at two aging treatments for this steel, Condition H 1150 and Condition H 1150M. Note carefully how the aging treatment affects the tensile strength of the finished alloy. Be very specific about heat-treatment and desired physical characteristics when ordering if you choose to use this alloy.

630, Condition H 1150 (Heated @ 1,150°F, 4 hours, Air Cooled)

Mechanical Properties

Hardness, Brinell	311
Hardness, Rockwell B	107
Hardness, Rockwell C	33
Tensile Strength, Ultimate	144,000
Tensile Strength, Yield	126,000
Machinability	40% (based on AISI 1212 @ 100%)

630, Condition H 1150M (Heated @ 1,400°F, 2 hours, AC then 1,150°F, 4 hours, AC)

Mechanical Properties

Hardness, Brinell	293
Hardness, Rockwell B	106
Hardness, Rockwell C	29
Tensile Strength, Ultimate	123,000
Tensile Strength, Yield	87,000
Machinability	45% (based on AISI 1212 @ 100%)

Chemical Composition

Iron	73.0%
Carbon	0.07% max
Manganese	1.00% max
Chromium	15.0-17.5%
Nickel	3.00-5.00%
Copper	3.00-5.00%
Niobium (Nb)	0.45% max
Tantalum (Ta)	0.45% max
Nb + Ta	0.15-0.45%
Silicon	1.00% max
Sulfur	0.03% max
Phosphorus	0.04% max

As you can see from the chemical composition, this is a complex alloy. This compositional complexity is what allows the alloy to harden by the precipitation of impurities within the iron lattice. The primary hardening elements in 630 are copper, nickel and niobium. The carbon content of this and other precipitation-hardening alloys is intentionally low to reduce embrittlement and increase toughness. 630 is a very strong stainless steel with better corrosion resistance than 416 and 410. However, it is also more difficult to machine than the other stainless steels we've examined. In fact, I suspect that the low machinability rating is the only reason why 630 is not widely used by both major manufacturers and custom barrel makers alike. As was the case with 410, you will want to seek the advice of your deep-hole drill manufacturer when selecting a cutting oil for this grade of steel.

As a martensitic stainless steel, 630 will become brittle at very low temperatures. However, it is far less susceptible to this type of embrittlement than 416R or even 410. It will also handle high temperatures for a short duration better than the other stainless grades that we have examined, but it will not handle this type of abuse as well as 4140 and still should not be used on firearms that will be subject to rapid-fire. In other words, 630 is the best available martensitic stainless steel for rifle barrels, at least in terms of mechanical properties. Unfortunately, it is the worst stainless alloy in terms of machining a smooth bore that will shoot straight without fouling. If you'd like to use 630 as your barrel alloy of choice, I strongly suggest that you go into it with an open mind and lots of patience. It may take quite a bit of experimentation to learn how to machine it effectively and efficiently. As a cut-rifling guy, it feels like blasphemy to say this, but button-rifling will probably prove to be a more satisfactory method with this alloy than cut-rifling simply because it is so much more difficult to machine than the other barrel steels. However, the stress-relief treatment mandated by the button-rifling operation may prove detrimental to the initial precipitation-hardening treatment. Check with the manufacturer of the steel before attempting any stress-relief operations on this alloy. They are the only ones who will know how to do it the right way– or if it should be done at all.

Along the same line of thought, look at the dramatic difference in the tensile strength of the two different heat-treatments. The mechanical characteristics of Condition H 1150 are right on the mark for a centerfire barrel blank, while Condition H 1150M is suitable only for muzzleloader barrels and would be positively hazardous if used to make

a centerfire barrel. Small changes in the temperature *or time* of aging can make a very big difference in the suitability of this alloy for rifle barrels. Again, be *very* specific about the desired physical characteristics when ordering 630 stainless steel. Also, be very cognizant of the time component of aging if you intend to perform any welding, brazing or silver soldering operations on the completed barrel. Over-aging will ruin all of your hard work.

Quality of Barrel Steel

As we have seen from the different chemical compositions and hardening treatments of the alloys listed above, everything must be just right to produce a bar of steel with the physical properties required for a rifle barrel. If either chemistry or hardness lies outside the range of tolerance, the safety and integrity of the barrel may be compromised. This concern has led to the production of certified "gun barrel quality" steel. The term gun barrel quality means exactly what it sounds like it means– that the bar of steel in your hands can be used to make a gun barrel. More precisely, it means that the chemical composition and/or physical properties of that particular run of steel have been verified by the manufacturer (or heat-treatment facility) before shipment to the end-user.

The downside of certifying the properties of a run of steel is that certification testing is expensive. To mitigate the cost of testing, a run of steel bars is usually certified by testing a sample bar at regular intervals, measured in thousands of pounds produced, during the run. The frequency of testing is determined by the specifications for the particular alloy and which property of the steel is being tested. Properties that are more likely to change during the course of a production run are tested more often than properties that are very unlikely to change unless something goes seriously wrong. The thinking is that if everything checks out to specs at the beginning of the run and every so often thereafter, then the whole run is likely to be good. This is sound reasoning that keeps the cost of barrel steel within reach of the budgets of barrel makers and the riflemen who buy and shoot their products. However, this type of hit-and-miss sampling can't guarantee that *none* of the rifle barrels made from that particular run of steel will contain voids or unwanted inclusions. Only testing the full length of every bar in the run could do that, adding considerable cost to the price of each barrel blank as an unavoidable side-effect. This is just one of the reasons why the yield strength of barrel steel absolutely *must* exceed, by a considerable margin, the force of the highest pressures the finished barrel will ever have to face. This extra strength provides a margin of error in case there are some minor imperfections in the steel.

As far as I know, there is only one exception to the practice of every-so-often certification testing, and that is 416R stainless steel. Crucible states that their 416R grade is subjected to "100% ultrasonic testing for reliable barrels". Full-length testing of every bar is a very sound practice with this alloy, but again, it sounds like another disclaimer to my inner pessimist. 416R barrel blanks would be cheaper if every bar wasn't tested full length, and cheapness is the name of the game in modern mass-production. So the fact that the manufacturer does test them full-length, without being asked to do so, seems like yet another sign that 416R is probably not the greatest stuff in the world for making a centerfire rifle barrel. But regardless of the misgivings of my inner pessimist, if you have a bar of Crucible's 416R in your hands, you can rest assured that the piece of steel you're holding, not just *some* of the bars in the production run, has been certified as being acceptable for the application.

While using only certified steel to make rifle barrels is a very good practice, there is one significant problem for the small-shop barrel maker. The fly in the ointment is the fact that certified steel of this sort is made in runs of 20 tons or more. Not only would buying that quantity of steel all at once break the budget, but it would also be impossible for the small-shop barrel maker to use all of it in two lifetimes. At 1.25" in diameter, a 20-foot round bar of steel will weigh in at 83.4 pounds. It will take 480 of these bars to hit the 20-ton mark. Furthermore, each 20-foot bar can be cut into 8 barrel blanks measuring 30 inches each. So a single 20-ton run of steel will make 3,840 rifle barrels! For a major manufacturer with a factory full of CNC machinery and hammer-forging machines, this is no problem. Those 480 bars will be gone in a few months. But for a small-shop barrel maker like me, who has only one lathe/mill and one barrel machine, both of which are manually operated, 20 tons constitutes an insurmountable pile of steel. The term embarrassment of riches doesn't even begin to describe the situation. Most of the steel would do nothing except sit around and rust for decades. There are only two reasonable methods for the small-shop barrel maker to get his hands on certified steel– buy his blanks from a larger custom barrel maker or buy small quantities of steel certified for other purposes.

The steel used for rifle barrels does not necessarily have to be specified as gun barrel quality. Remember that all of the alloys we examined (except 416R) were developed for purposes other than making rifle barrels. What this means is that you may be able to get small quantities of steel that have been certified for other purposes. For example, you may find a local steel distributor who has 4140 chrome-moly steel that has been certified for truck axles or some other purpose. It doesn't matter *why* the steel was certified, as long as it has been certified and found to have the correct chemistry and mechanical characteristics for use as a rifle barrel. If our hypothetical supply of 4140 has been certified to have a hardness of RC 30 with an ultimate tensile strength of 140,000 psi and a yield strength of 116,000 psi with no voids or inclusions, what does it matter that it was originally intended to be made into a truck axle or something else? The steel is what it is regardless of our intentions for it or the labels we place on it. With more steel mills shutting down and minimum quantities for orders continually rising, the small-shop barrel maker may soon be left with no choice but to use steel that, while suitable for making rifle barrels, is not bestowed with the magical moniker "gun barrel quality". Just remember that barrel blanks can't read and have no idea what sort of labels we attach to them. They only know what they are made of and what kind of abuse they can handle.

As a custom muzzleloading barrel maker, my own solution to finding small quantities of certified steel is to use Niagara LaSalle's Stressproof 1144. All runs of Stressproof (and all other brands of cold-drawn 1144) are subject to ATSM A311 Class B specifications. This is the regulation that requires seams no deeper than .0015" for every $^{1}/_{16}$" in diameter. It also requires one tension test to determine tensile strength, yield strength, reduction of area and elongation for every 50,000 pounds of 1144 produced. As mentioned briefly in the section on resulfurized steel, Niagara LaSalle voluntarily tightens the seam depth tolerance to .0010" for every $^{1}/_{16}$" in diameter. Additionally, they also perform one machinability test for every 10,000 pounds of 1144 produced. Niagara LaSalle states that the machinability test "is very sensitive to effects associated with the basic nature of the steel, such as tensile properties, hardness, metallographic differences in structure and inclusions, and variations in chemical composition." If, at any one of the

10,000 pound intervals, a bar of Stressproof fails the machinability test, then the entire run is rejected. Mind you, this certification testing is not done only on special gun barrel quality runs. It is performed on *every* run of Stressproof. To my mind, this is about the closest thing to free certification that you can get for muzzleloader barrel steel. And, even more importantly, Stressproof can be bought in very small quantities. I've gone to my local steel distributor and ordered as little as *one* 20-foot bar when that was all I needed to keep me busy for a while. Another thing that I like about this alloy is the small amount of silicon that is added to the mix. Remember from our discussion of 4140 that a bit of silicon will help prevent the steel from forming voids as it cools from the initial pour. That gives me just a bit more assurance that I won't spend days making a barrel only to have it burst during proof-firing.

Now let's talk about how we can be sure that a particular rifle barrel is safe to fire when it came from a certified run of steel in which every bar was not tested full-length. The certification that was done prior to machining the bar of steel into a finished barrel does two things: it tells the barrel maker that he is, indeed, getting what he's paying for in terms of chemical composition and it gives him a piece of paper that will help cover his backside, in a legal sense, if one of his barrels happens to fail. The *real* certification takes place when a proof load is fired in the completed barrel. Proof-firing is the only way to *know* that a bar of steel is suitable for use as a rifle barrel. Not only does the proof load certify that the steel has the correct mechanical properties for the job, it also certifies that the barrel maker didn't profile the walls of the barrel too thin or draw the strength and hardness with brazing or soldering operations too much to contain the breech pressure of a maximum load. It also proves that there are no catastrophic voids or inclusions in *that particular piece of steel,* and that is something that certification testing at intervals cannot do. We will discuss proof-firing procedures and loads in more detail later. For now, just remember that, no matter whether the steel used to make a barrel is certified gun barrel quality or not, the proof-firing step *must not* be skipped– not ever.

CHAPTER 9: Proof-Firing

Rifles impart motion to their projectiles by igniting a violent deflagration beneath them in an enclosed space. This causes, by necessity, very high pressures. The high-pressure gas generated by the burning gunpowder is able to launch the bullet from the barrel at high velocity by applying considerable force to the base of the bullet. This is all well and good, but the gas also pushes with the exact same amount of force against the breech of the rifle and the walls of its barrel. And if the barrel is not strong enough to stand up to this force, the barrel bursts and sends shrapnel flying indiscriminately across the landscape. This is a very dangerous situation that should be avoided at all costs. The only way to be reasonably certain that a particular rifle barrel will not fail when fed a steady diet of normal loads is to feed it a load that has intentionally been made far more powerful than any other load the barrel will ever be asked to digest. This procedure is called proof-firing and its goal is to cause a faulty barrel to burst, or at least swell to the point of becoming completely unserviceable, before anyone ever fires a round through it from the shoulder.

With the firing of a single proof load, you are verifying: the strength of the raw material, the thickness of the barrel walls, the integrity of the installation of the receiver or breech plug and, to a certain extent, the dimensional accuracy of a centerfire barrel's chamber and bore. There is no means other than proof-firing to know for certain that a particular rifle will be safe to fire from the shoulder. Sure, measuring instruments and gages can be used along with the yield strength of the steel to, theoretically, determine whether or not the barrel is sound. You can even use X-ray or ultra-sound to have a peek inside the barrel to determine if any internal flaws are present. But, even in the technology-filled 21st Century, the only way to be absolutely certain that a specific barrel is structurally sound is to subject it to a ridiculously heavy load that generates forces of equally ridiculous magnitude. The reason it is called "proof-firing" is because it *proves*, beyond any reasonable doubt, that the barrel is satisfactory for its intended use.

While the need for proof-firing is universally accepted among all cultures (at least those cultures which are civilized enough to trust armed citizens), the standards of proof do vary somewhat in different regions throughout the world. Standards of proof can also vary depending upon the caliber of rifle being tested and the normal pressures to which it is subjected. I am not employed at a ballistics research facility, nor do I have the sensitive instrumentation necessary to conduct my own ballistic testing. So, as far as I can say with any measure of credibility, it doesn't matter which set of proofing standards you choose to follow. The important thing is that you do follow *some* standard. The standard of proof that you choose to follow will be largely dictated by the equipment you have on hand to measure your compliance. However, it is probably wise to at least attempt to use the standard that was originally established for the caliber and chambering of the specific barrel that you are proving. For example, if you are proof-firing a barrel chambered for the 7 × 57mm Mauser cartridge, it would make sense to use the Commission Internationale Permanente (CIP) standards for proving that particular barrel because that is the original standard for the cartridge. However, without the sophisticated equipment needed to conduct internal ballistic testing, it may not be practicable to use a particular proofing standard because you won't be able to tell whether or not you are in compliance. Most proofing standards are based on maximum chamber pressure produced by the proof

load, but these standards do you no good if you don't have loading information for the proof cartridges or a pressure measuring device to determine when the specified pressure has been reached. Fortunately, there are other alternatives for assembling proof loads that do not require verification by a ballistics laboratory.

Centerfire Standards of Proof

Centerfire rifles are used globally by every nation on the planet. Granted, the residents of some nations are not allowed to own firearms, but every nation's military is equipped with centerfire rifles. Because of the universality of centerfires, there are several different organizations throughout the world that have established proofing standards for centerfire rifles. There is considerable agreement between the standards adopted by the various institutions, but they are not always in complete agreement. For instance, the Sporting Arms and Ammunition Manufacturers' Institute (SAAMI) requires only one proof cartridge to be fired in an individual barrel while the CIP demands that two proof loads be fired. However, there does seem to be one constant among the different proofing standards– proof loads for centerfire rifles should generate at least 30% more pressure than the heaviest standard service load.

For the proofing of barrels chambered for domestic American cartridges, the standards of SAAMI should be adhered to if at all possible. This organization recommends different magnitudes of overload to prove different cartridges. The recommended proof loads can vary in intensity from 30% over normal pressure to as much as 40%. If adhering to the SAAMI standards, you will need to look up the proof load information for the desired cartridge to make sure that you are actually using a proof load and not just an extremely heavy load.

The European organization that determines proofing standards is the CIP. Their standards call for a load that develops 30% higher than standard pressure regardless of the caliber or cartridge that is being tested. However, as mentioned before, they also require that two proof loads be fired in each barrel. But if you use the European standard, at least you'll know how much pressure you're supposed to be applying to the barrel walls.

The British have their own standards which can vary from 30% all the way up to 45% more pressure than the standard load for a given chambering. So, if you're going to build a rifle chambered for one of the classic British big game rounds, you will need to find the specific proofing standard for that cartridge.

All of this is good to know, but it really won't do you much good if you don't have the instrumentation to measure pressure. No handloading manual lists loads that are so far above normal operating parameters. If you're lucky, you'll be able to find someone in the right circles who is willing to give you load data for proof loads in the rifle you are trying to prove. But with liability lawsuit lawyers lurking about on every street corner, always on the lookout for an easy paycheck, don't bet the kid's college fund on the chances of finding someone who is willing to provide you with information that is inherently dangerous. Although the small-shop barrel maker should make an honest attempt to acquire a legitimate proof load based on chamber pressure, it may not always be possible to do so. Fortunately, the regulating organizations have adopted, although certainly not universally, other standards besides peak chamber pressure that can be used for proof-firing rifles.

One of these alternative proofing procedures involves using a load that generates a muzzle energy that is 10% higher than the muzzle energy developed by the most powerful standard loading for a particular cartridge. Since muzzle energy is based solely upon muzzle velocity and bullet weight, both of which the barrel maker can easily measure, this method has real applicability in the small-shop environment. This proofing standard is not as different from the pressure standard as it seems at first glance. The reason is that, generally speaking and depending upon the case capacity and bore diameter in question, it will normally take nearly 30% more pressure to increase the muzzle energy by 10%. The only real difference between this method and the other is that there is no way to tell exactly how much the chamber pressure has increased. But regardless of the somewhat ambiguous nature of this procedure, it is the most practical method available for the small-shop barrel maker to establish proofing procedures that he can actually follow without undue expenditure of capital. In this instance, the data in handloading manuals can be very useful. You can calculate the average rate of increase in muzzle velocity for each additional grain of a given powder added to a load and then extrapolate the charge that would be required to achieve the target velocity. Err on the side of caution and estimate the required load to be a little light. The goal is to *test* the integrity of the barrel, not *destroy* it. When proof-firing the rifle, fire the bullet over a chronograph to check the actual velocity. If the proof load met or exceeded the target velocity, you're done. If it's not quite high enough to reach the required energy figure, increase the charge by a grain or two and repeat the process. In a sense, this will also meet the CIP standard for two proof loads to be fired in every barrel. The thing to remember is that the proof load must generate 10% more energy than the energy generated by the *most powerful load available*. This load may be heavier than any load that you intend to use, but it's the correct energy figure to use if the proof is to be done properly. Do some research and find out what the maximum energy figure is for safe loads in your chosen cartridge and set that as the mark to beat.

In some instances, it will be not be possible to create a proof load that will generate 10% more energy than maximum. Two circumstances that could prevent increasing the energy of the load to the required level are limited case capacity and/or strength limitations of the rifle's action. No need to fret, however, because there is yet another standard that can be used in these situations. According to this procedure, a normal maximum powder charge can be used for proofing if the weight of the projectile is increased 10% above the bullet weight used in the standard load. One case in which this proofing method may be the only option is in the case of the .458 Winchester Magnum. This cartridge is notorious for its limited case capacity and the vast majority of powders with suitable burn rates require compressed loads to reach maximum pressure. Since the cartridge case is already stuffed to the gills with a normal maximum load, there is no way you will be able to squeeze enough additional powder into the case to generate 10% more energy than the standard load. The task would be possible if you switched to a faster-burning powder than those that are normally employed, but there is no published load data for these quick propellants (at least not for maximum loads) that you could use as a guide. However, thanks to Woodleigh, adhering to the rule of using a normal charge with a 10% heavier projectile is quite simple. Woodleigh manufactures .458" bullets in weights all the way up to 550 grains. A 550 grain bullet just happens to be exactly 10% heavier than the normal 500 grain bullets used in this cartridge. So, if you've got your

heart set on building the elephant rifle you've always dreamed of and you want it to be a .458 Winchester Magnum, an acceptable way to proof your new barrel is to load a 550 grain bullet over a maximum powder charge for a 500 grain bullet. The one major concern that you have to keep in mind if you use this procedure is that the heavyweight bullet *must be seated to the same depth as the lighter, standard bullet*. If you seat the heavy bullet to a different depth than the bullet for which the load was developed, you are, in effect, either lengthening or shortening the case and changing the case capacity. Case capacity is one of the most important variables that affect chamber pressure, so the seating depth absolutely must be the same as that called for in the normal load. And again, there is no way to know exactly what the pressure of the load will actually be.

The other situation that may call for this proof-firing procedure is in the case of a rifle action that may not be strong enough to contain the pressures required to develop 10% more muzzle energy than a standard load. This is often the case with double-barreled rifles. Double-barreled rifle actions are not particularly strong, at least not when compared to bolt-actions. Yet they are often chambered for cartridges that churn up dead-serious muzzle energies. When dealing with the relatively weak actions and monstrous energies associated with this type of rifle, it is not prudent to increase velocities by the magnitude required to generate substantially greater energy. Case capacity definitely isn't at issue with any of the Nitro Express cartridges, but the merit of risking damage to a very expensive, hand-fitted rifle certainly is. But, thanks again to Woodleigh's heavyweight bullets and the fact that double-rifles are regulated for one, and only one, powder charge/bullet combination, developing a proof load for these rifles is a snap. As with the previous example, seating depth must remain constant. The one additional requirement for the application of this proof procedure is to fire two of these proof loads in each barrel. This requirement for two proof loads per barrel also applies to rifles that are adorned with a single barrel, such as the .458 Winchester mentioned above.

If you need to proof-fire a caliber for which extremely heavy bullets are not available or you simply don't want to buy an entire box of expensive bullets just to fire two proof loads, you can also make your own custom bullets for the proof-firing. These bullets do not need to be fancy or particularly aerodynamic. They just need to fit in the cartridge case and down the bore. There are two options in raw material for fabricating the proof bullets. The first and simplest option is to make the bullets out of a hard lead alloy. The bullet blank can be cast using any appropriately sized metal pipe as a mold, and then cut and turned to size on the lathe. This option would be appropriate for cartridges developing relatively low pressures and velocities. Custom lead bullets to be used for proving could be fabricated to seat the bearing surface of the bullets snug against the rifling to make sure that full proof pressure is achieved. However, if pressures will be much over 40,000 psi or velocities will exceed 2,300 fps, the proof bullets should be made of stouter material, like brass. If using brass for the proof bullets, it would be a good idea to cut driving bands on the bullets and seat them off the lands a bit to ensure that pressures don't get higher than they are supposed to be. Again, you are not trying to destroy your new barrel, you are merely trying to prove that it is safe for all normal loads. No matter what material the proof bullets are made of, they do not need to be elaborately shaped. Simple dual-diameter cylinders will suffice. The major diameter should be the same as the barrel's groove-circle diameter. The minor diameter should be a few thousandths of an inch under the land diameter. The length of the bearing surface (major

diameter section) will be dictated by the required seating depth (the same as the conventional bullet in the normal load), the length of the barrel's throat, and the intended gap between the bearing surface and the rifling. By using simple dual-diameter bullets, the required length dimensions of the two sections of the bullets will be easy to calculate using the density of the material. The proof bullets can certainly be made in a conventional bullet shape, but determining the dimensions required to achieve the desired weight will be far more complicated. Remember, the proof bullets are only being used to generate higher pressures than normal. They don't need to shoot straight, so aerodynamics (or lack thereof) are of no consequence.

Muzzleloader Standards of Proof

The information concerning proof-firing information for centerfire rifles is pretty easy to find and there are several different options available to accomplish the proofing that cover most conceivable scenarios. By contrast, there is very little information available regarding the proofing of a muzzleloader barrel, or black powder cartridge rifles, for that matter. The reason for this paucity of information concerning the proof-firing of charcoal-burning rifles is that *proof-firing is not required for muzzleloaders here in the United States*. That's right, friend. When you stuff your brand-new in-line muzzleloader with a magnum charge of powder and squeeze off your first shot, *that is most likely the very first shot that has ever been fired in that barrel.* Even if the barrel was imported from Europe where they must be proof-fired, a look at the proof markings will probably reveal that the proof load used only generated about 10,000 psi. Considering the fact that magnum, in-line muzzleloaders are often stuffed with powder/projectile combinations that generate 30,000 psi, you are, in a very grim and real sense, playing Russian roulette when you fire that first shot in an unproven, or inadequately proven, barrel. And there have been documented cases of sad, serious consequences befalling hapless chaps who unknowingly fired the proof loads in their virgin barrels while their hands, faces and other sundry tender bits were in dangerously close proximity. A lot of knowledgeable folks have been making a lot of noise about this unacceptable situation for decades, yet we still have no rules of proof for muzzleloaders here in the States.

Fortunately, our counterparts on the European continent have a little more common sense (at least in this instance) and the CIP has adopted, and vigorously enforces, a set of proofing standards for muzzleloading arms. The standards of proof for black powder arms as laid forth by the CIP for high-pressure (20,000 psi service loads) rifles are listed in the chart below.

Caliber	*Proof Load*		*Maximum Service Load*	
	Powder (grains)	*Bullet (grains)*	*Powder (grains)*	*Bullet (grains)*
44	146.6	293.2	92.6	231.5
45	154.3	293.2	92.6	246.9
50	200.6	370.4	123.5	308.6
54	223.8	432.1	138.9	432.1
58	254.6	478.4	154.3	478.4
69	308.6	694.4	185.2	617.3

Weights converted from grams to grains and rounded to tenths

These proofing standards are certainly better than having no standards at all, but there is something about them that struck me as odd. If you compare the maximum service charge of powder to the proof charge, you will find that the proof charge averages out at about 1.6 times the maximum service charge and no proof charge for any caliber differs from this figure by much. However, in the case of the proof bullet weight compared to the maximum service bullet weight, the proof weights are anywhere from 1.00 times the service weight all the way up to 1.25 times as much. If the lighter proof bullets were used with proportionately heavier proof powder charges, this wouldn't be so perplexing. But since the powder charge percentage increase is uniform across the different calibers, I am left at a complete loss as to why the same doesn't apply to the bullet weight. In any case, the CIP standards do not list every caliber for which I wanted to make barrels. They also do not list service loads as heavy as the loads I had in mind for my barrels. For these reasons, I decided to come up with my own formula for proof loads based on their standards. Since the 60% increase in powder charge is uniform across all calibers, I chose to simply adopt this figure for my own use. For the proof bullet weight, I decided to use the heaviest percentage increase, 25%, for proof bullet weight listed for any caliber. By using these figures, I was able to calculate proof loads for any caliber and maximum service charge that I chose. The proof load figures that I have established for my own barrels are listed below.

Caliber	*Proof Load*		*Maximum Service Load*	
	Powder (grains)	*Bullet (grains)*	*Powder (grains)*	*Bullet (grains)*
58 (24 bore)	240	665	150	530
62 (20 bore)	265	755	165	605
69 (14 bore)	320	940	200	750
72 (12 bore)	370	1,020	230	815
76 (10 bore)	440	1,140	275	910
82 (8 bore)	520	1,325	325	1,060

There is one thing I should make clear: the loads listed in the Maximum Service Load column are not actually service loads at all. My objective in adopting these standards was to ensure that my barrels got the stiffest test possible without unnecessarily risking a catastrophic failure with a senselessly heavy proof load. The heaviest powder charges for muzzleloaders are used behind patched round balls. If heavier conicals are used, the service powder charge must be reduced to keep pressures within the operating range of the system. So, in the interest of developing proof loads that are stout enough to really test the barrels while remaining within the bounds of reason, I utilized a hybrid service load to calculate the proof load. The bullet weight listed under the Maximum Service Load is indeed the maximum recommended conical bullet weight for each caliber. However, the powder charge listed under the Maximum Service Load is the maximum charge that can be used with *round ball loads* in my barrels and *should never be used in conjunction with a heavy conical*. I just want to make sure that is absolutely clear, especially to those of you out there who happen to own one of my barrels. Again, this was done to provide the heaviest reasonable proof loads for my barrels without going way beyond the bounds of common sense. In practice, my proof loads work out as follows: powder weight 160% and bullet weight 163-233% above *maximum round ball loads*; powder weight 171-189% and bullet weight 125% above *maximum conical bullet*

loads. These proof loads are obviously serious overloads and I feel that they are entirely adequate for definitively proving the safety and integrity of my barrels. I can't say for sure what kind of pressure my proof loads generate. Considering the fact that the normal service loads peak at around 20,000 psi, I'd wager that the proof loads run in the neighborhood of 30,000 psi in all calibers, perhaps a bit higher. This pressure level is sufficiently high to prove barrels for sidelock muzzleloaders and, in fact, it far exceeds the standard percentage increase of pressure used to prove centerfire barrels.

When I think of a muzzleloader, I picture a rifle that is equipped with a hardwood stock, an exposed hammer, a side-mounted lock that is inlet directly into the wood and iron sights atop the barrel. There are many who feel the same way, but we are the few. When most contemporary black powder hunters think of a muzzleloader, they envision a synthetic stock, brushed stainless steel, a centerfire-like receiver and, most certainly, a riflescope perched above the whole thing. Considering the popularity of the modern, in-line 50 caliber muzzleloader, I should probably take the time to discuss a suitable proof load for this arm even if I have no plans to build one of these new-fangled wonders myself. Normal service loads for these rifles unleash pressures that run in the range of 25,000 to 30,000 psi. This is about the same pressure as a sensible proof load for a sidelock. The same basic rules of proof will still apply, but the pressure produced by the appropriate proof load will certainly be much higher.

Most of the current crop of 50 caliber in-lines are loaded with up to 150 grains of powder, often in the form of pellets. This seems to be the standard maximum service powder charge. However, the weights of bullets that are placed over that charge vary widely. If you want to make a 50 caliber in-line, I would suggest proofing it for a maximum service load consisting of the 150 grain magnum charge of powder and the heaviest bullet available for a rifle of this caliber. The heaviest 50 caliber bullet I have been able to find is the PowerBelt Steel Tip Dangerous Game Bullet. This projectile weighs in at 420 grains. The proof load that I would suggest for a magnum rifle that can be loaded with this bullet is 240 grains of powder and a 525 grain bullet. That is the equivalent of a *very* stout round ball load for a 12-bore (72 caliber), and it will definitely generate enough pressure to test the barrel's integrity. If you'd like to conduct an informal check of the suitability of your mass-produced 50 caliber in-line for magnum loads, call the manufacturer and tell him you're going to proof-fire the rifle with this load and ask if he'll give you a refund if it blows up. If he tells you that proof-firing your rifle is an excellent idea and, further, that you should go ahead and proceed as planned, then your rifle is likely pretty well-built. If, however, he starts talking about how the rifle really isn't designed for that, or some other such flapdoodle, then it's probably not all that safe to fire magnum loads in the thing and you may want to ease up on the throttle a bit before your next trip to the whitetail thicket.

The fabrication of bullets heavy enough for a muzzleloader's proof load is a very simple undertaking. To cast the heavy lead slugs, I have finally settled on the practice of using the cut-off end of the barrel blank as a bullet mold. After cutting off the muzzle end of the barrel to remove any slight imperfections in the bore in that section, simply stand this stub vertically on a flat plate of steel. Voila, instant bullet mold. Just pour some molten lead into the bore. Once cast, the slug will shrink slightly so that it will easily slip from the bore. Cast it a bit longer than necessary to achieve the weight that you want and then face it to length in the lathe. The final step is to place the slug in the bench vise

(perpendicular to the jaws) between aluminum soft-jaws and give it a gentle squeeze to bump up the diameter a bit. This will allow it to be swaged tightly into the bore when it is loaded over the powder charge, just like a standard bullet that is engraved by the rifling when loaded. The length of slug needed to hit the target weight is very easy to calculate because the slug is a simple cylinder. Again, the projectiles used for proof-firing don't need to be sleek and accurate. They just have to provide enough resistance to the expanding propellant gases to build up pressure. The proof slugs produced by this method fit the bill very well.

One thing about proof-firing muzzleloaders that is not simple is getting the things to go off without the sophisticated lockwork designed for the task. Contrary to what you have heard, percussion muzzleloaders are *not* always easy to set off. We've all heard the warnings about how something as seemingly innocuous as a bit of drifting ash from a campfire can ignite a horrible calamity if there's a loaded muzzleloader within a 20-foot radius of said wayward ash. Well, I'm telling you right here and now that it ain't so. I will spare you a lengthy description of all of the various, and seemingly excessive, procedures I have experimented with to try to set off the proof load in a muzzleloader barrel. But I will tell you that only one method results in a satisfying boom *every* time. Suffice it to say that you will not believe how difficult it is until you've tried it yourself. In an effort to spare you the frustration I have experienced in this endeavor, here is the *only* procedure I have found (other than cocking the hammer and squeezing the trigger of a finished rifle) that will *reliably* set off a percussion muzzleloader barrel on the first try:

- Place the barrel in the proof-firing fixture and secure it snugly.
- Load the barrel with the proof load.
- Place the fixture and barrel in front of a backstop suitable for catching the proofing slug.
- Remove the nipple from the breech plug and make certain that there is powder directly under the nipple.
- Replace the nipple and build a little dam around it with masking tape.
- Split a one inch length of cannon fuse lengthwise.
- Place a piece of paper on a level surface and roll the split fuse between your fingers over top of the paper. The paper will catch the flash powder that falls out of the core of the fuse.
- Slowly and carefully shake or scrape the flash powder off of the paper *directly into the nipple orifice.*
- Stop occasionally and use a nipple pick to push flash powder to the bottom of *and through* the nipple. The idea is to build up a solid column of flash powder from the top of the nipple all the way down to the main charge.
- When the nipple is packed with as much flash powder as it can hold, tape a 12" section of cannon fuse to the top of the barrel with one end of the fuse touching the top of the nipple. A couple strips of masking tape are all that's needed.
- Pour a mound of extremely fine *smokeless powder* (I use H-110) into the dam of masking tape around the nipple. Keep pouring until the nipple and the end of the fuse are completely covered.
- Light the fuse and run for cover.

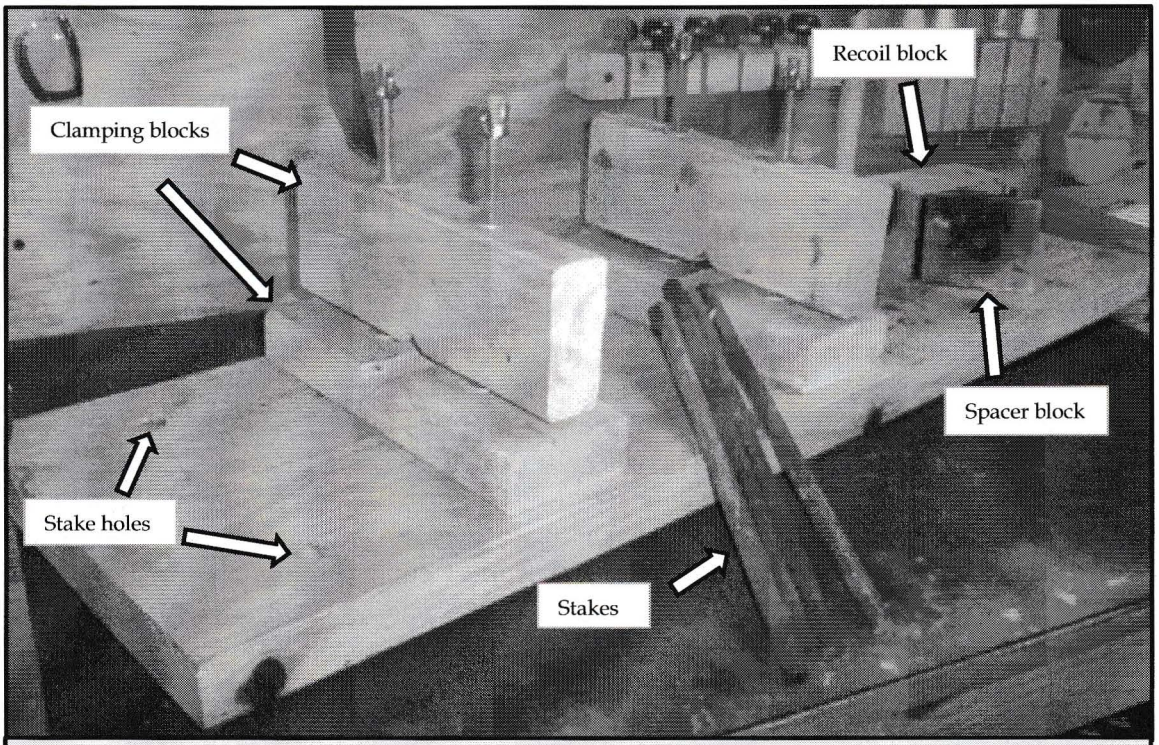
See, I told you it would seem excessive. But trust me, every single step in this procedure is an absolute necessity because the length of the nipple ensures that the spark of the fuse will be quite far from the powder charge. Of particular importance are the steps involving the packing of the nipple with flash powder and the use of smokeless powder in the dam. Packing the nipple ensures that there is a continuous column of flammable material between the fuse and the main charge. Without the flash of an exploding percussion cap, there is no other reliable way to get a hot enough flame to the powder to ensure ignition. When unconfined, smokeless powder burns quite slowly and progressively. The use of smokeless powder in the dam provides a long enough burn time to ensure ignition of the flash powder. If you need to proof-fire a flintlock barrel, setting off the charge will be far easier. Putting a small pile of flash powder over the flash hole and using the nipple pick to pack it full will be sufficient to provide reliable ignition.

Proof-Firing Fixtures

I was recently watching a television show about a gunsmith shop. During one particular episode, one of the gunsmiths was rebarreling a customer's rifle from a small-bore magnum caliber to a dangerous game caliber. Our intrepid hero did the actual conversion quite well. However, he completely lost my admiration when it came time to proof-fire the new barrel. This nimrod loaded the barreled action, pointed the muzzle towards a catch-barrel designed for the purpose, and then proceeded to test-fire the rifle *while holding the barrel in his bare hand!* This act is so unbelievably stupid that I really don't know what to say about it. What really gets me is the fact that the guy was knowledgeable enough to realize that a new barrel needs to be proof-fired, yet he didn't see a problem with holding the thing in one of the hands that he relies upon to make a living while doing it! Think about it: you're proof-firing the barrel because *you don't know for sure* if it's strong enough to stand up to a normal load. The last thing anyone with a lick of common sense would want to do is wrap his grubby fist around the chambered portion of the barrel, the section that must contain the *peak* pressure of the load, while wondering if the thing is going to blow off half of his arm when it fires. *Do not* proof-fire your barrels this way, unless you would like to have a nifty new nickname like "Stubby" or maybe "Ol' Nub". Of course, if you have to be told this seemingly obvious point, then you probably don't have any business trying to build a rifle in the first place. Perhaps stamp collecting would suit you better? At least you wouldn't be a menace to society…

Another bad idea (although not completely simple-minded like the example above) is propping the fully assembled rifle in an old tire and pulling the trigger with a string. In this case, the guy doing the proof-firing is not in harm's way, but the rifle's stock certainly is. If the barrel gives way under the pressure of the proof load, chunks of barrel steel are likely to go flying. If the rifle has been assembled in the stock prior to proof-firing, there is an extremely good chance that the stock will be turned into kindling by the shrapnel from the burst barrel. Now you will need a new barrel *and* a new stock. If, however, the stock is kept out of harm's way, then all that will need to be done to get the rifle back into commission is to fit a new barrel. Furthermore, even if the barrel survives the proof-firing, there is a *very* good chance that the primer will not. If the primer lets go, the escaping high-pressure gas may do just as much damage to the stock as a bursting barrel would have done.

The best way, by far, to proof-fire a rifle is through the use of a purpose-built fixture. The fixture does not need to be elaborate. A plank of wood will suffice for the base. A pair of wooden clamping blocks is attached to the base. The blocks function in exactly the same fashion as a barrel vise used to screw a rifle's action onto the barrel. The lower set of blocks is screwed directly to the base. The clamping blocks have circular or triangular cut-outs that fit around the barrel. All-thread is cut to length and passed through the base and the blocks. After the top clamping block is put into position over the barrel, wing nuts are spun onto the all-thread and tightened down to firmly lock the barrel in position. If a rifle or muzzleloader barrel that produces a significant amount of recoil is to be proof-fired in the fixture, then some sort of recoil block needs to be added to the rear of the fixture to prevent the barrel from scooting out the back door. This block needs to be made of strong hardwood and firmly anchored to the base with strong bolts. In the



The proof-firing fixture is nothing elaborate, but it doesn't need to be to perform its simple function. Note the powder burns on the well-used spacer block.

case of a fixture for muzzleloader barrels, the recoil block can be very simple with a square face. In addition, I also use a small piece of ¾" plywood as a spacer block between the recoil block and the barrel. This plywood square has a hole drilled through it that slips over the breech plug's hook. The hooks are pretty tough, so this addition does more to protect the recoil block from being split by the hook than it does to protect the hook from being damaged by the block. If the fixture will be used to fire centerfires, the shape of the block may need to be more elaborate to ensure that delicate tangs and other features of the action are protected from the recoil forces. The recoil block should only make contact with the recoil lugs or other surfaces on the action that are specifically designed to absorb recoil. One last consideration for the proof-firing of heavy-recoiling calibers is keeping the fixture itself in place. I drilled four ½" holes through the base of my fixture. When the fixture is in position and ready to go, I drive four ½" steel stakes

through these holes and into the ground to keep the fixture from scooting or flipping when the proof load discharges. There's no sense in risking unnecessary damage to the brand-new barrel by allowing the possibility for it to go skittering across the ground.

After the proof load has been fired, the barrel needs to be inspected to ensure that it did indeed pass the test. If the barrel bursts, this inspection will be quick and easy because the failure of the barrel will be quite obvious. However, the barrel walls could have suffered slight plastic deformation that is not so obvious. To check muzzleloaders for this type of damage, I take measurements of the bore both before and after the proof-firing. Both sets of measurements should be exactly the same. In addition, I also push a tight lead slug through the bore before proof-firing to swage it to the exact dimensions of the bore. After proof-firing, the same slug is again pushed through the bore. If any loose spots are encountered, then that portion of the bore has expanded and the barrel has failed the proof. If you have an air gage, by all means use it instead of the lead slug. These same checks of the bore should also be made on a centerfire barrel. However, the chamber dimensions will also need to be verified. Make a chamber cast before proof-firing and write down the critical dimensions of the cast. After the proof-firing, make another chamber cast and compare the dimensions to the dimensions of the unproven chamber. Again, the measurements should match exactly. And finally, the headspace needs to be checked again. If everything is as it should be, your rifle has passed and is ready for the range and field.

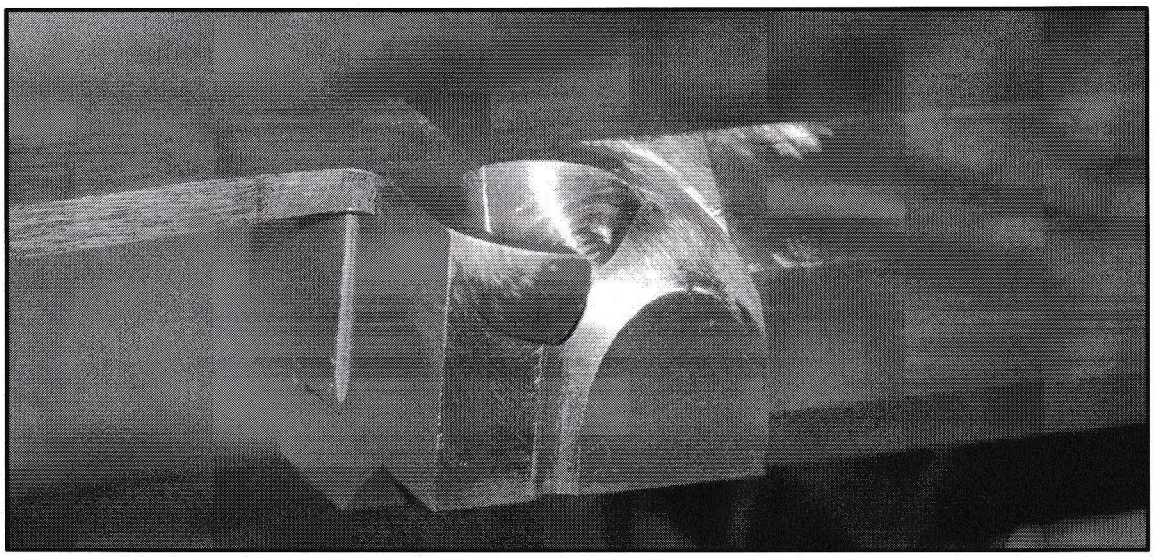
In order to pass the lead slug all the way through the bore of a muzzleloader barrel, the breech plug needs to be removed. This is an excellent time to check the fit of the plug against the internal shoulder of the barrel. When you pull out the breech plug and examine its face, you should see a neat, perfect circle of fouling in the center of the plug. Beyond this black circle, you should see nothing but clean, shiny steel. If there are any fouling smudges extending beyond the interface between the face of the plug and the barrel shoulder, then your breech plug is not fitting as tightly as it should. This means that high-pressure gas found its way into the threads during the proof-firing and you are very lucky that the thin walls in the threaded portion of the barrel did not burst under the pressure of the proof load. In this case, the breech plug will need to be refit to the barrel. You do not need to fire another *proof* load in the barrel because the barrel itself has already passed. However, you would be wise to fire a normal load in the barrel after refitting the plug so that you can check for fouling/gas leakage into the threads again.

The Reward

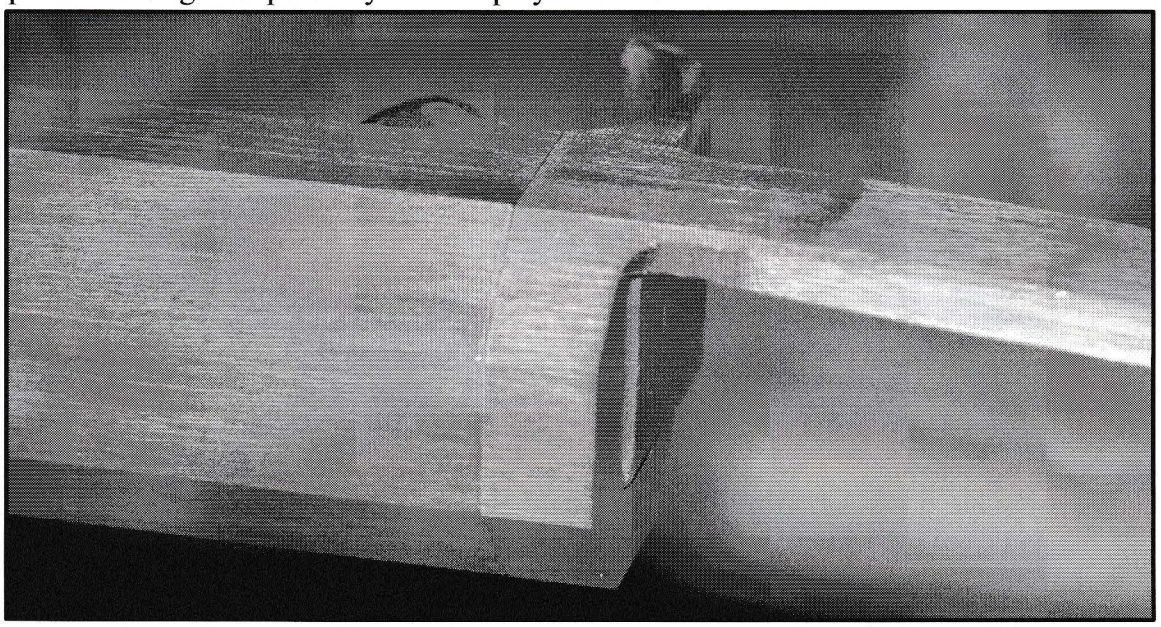
Here are a few pictures of what can be done by a riflesmith who sets his mind to the task of building his own barrel machine and crafting his own barrels. This sort of work provides a level of satisfaction that is hard to describe. The closest I can come is this: think back to the time when you first began loading your own centerfire ammunition. Remember how great it was to see those little, tiny groups appear in the bulls-eye for the first time? And I know you remember the feeling when you felled your first big game animal with a load that you assembled yourself. Now imagine, in addition, how it would have felt if you had also chambered and installed the barrel on the rifle yourself. And, finally, try to picture how it would have felt if you had made the machine and tools that made the barrel. Having made this fantasy a reality, I can tell you that it feels like a very worthwhile achievement. It also feels like complete independence. Keep

in mind that I am a riflesmith, not a professional photographer, so the pictures aren't quite as good as I would like them to be. Regardless, I hope that they'll inspire you to make your own dreams come to life. If so, then our time together has been well-spent.

The following are some selected pictures of an 8-bore barrel that I made for a customer. The barrel is a complete custom job. I made the barrel, breech plug and standing breech entirely from scratch. All surfaces have a file finish. No sense in polishing the metal before the rifle is even built…

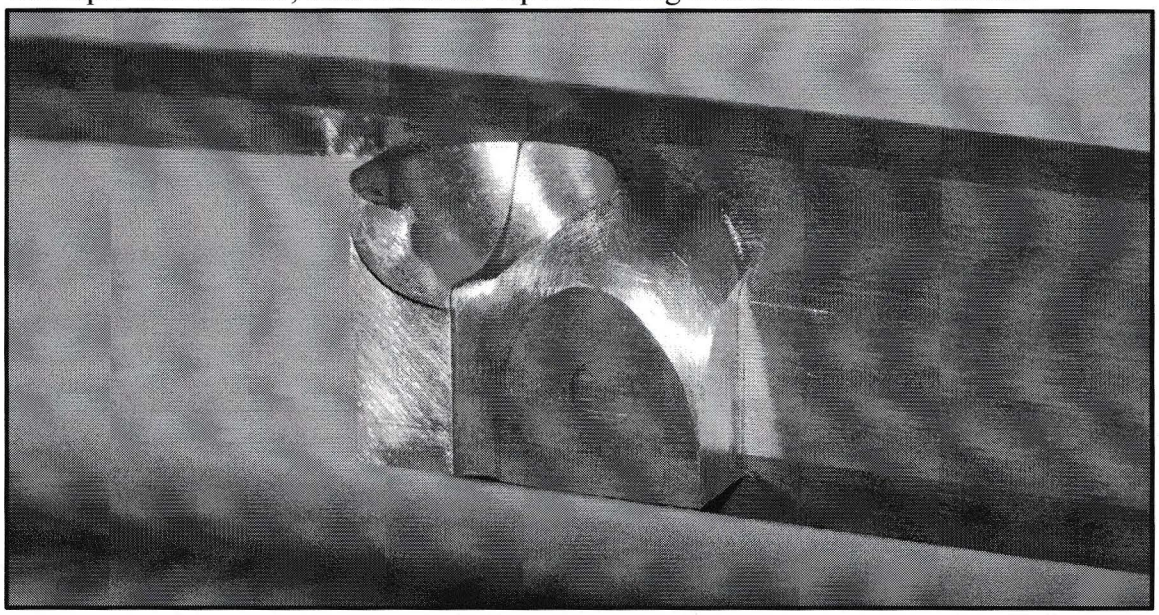


This is a close-up detailing the fit between the breech plug, standing breech and the barrel. Note especially how tight the side-to-side fit of the breech plug's lug is to the standing breech recess. This is what you want– the job isn't done properly until these two parts mesh together perfectly with no play whatsoever.

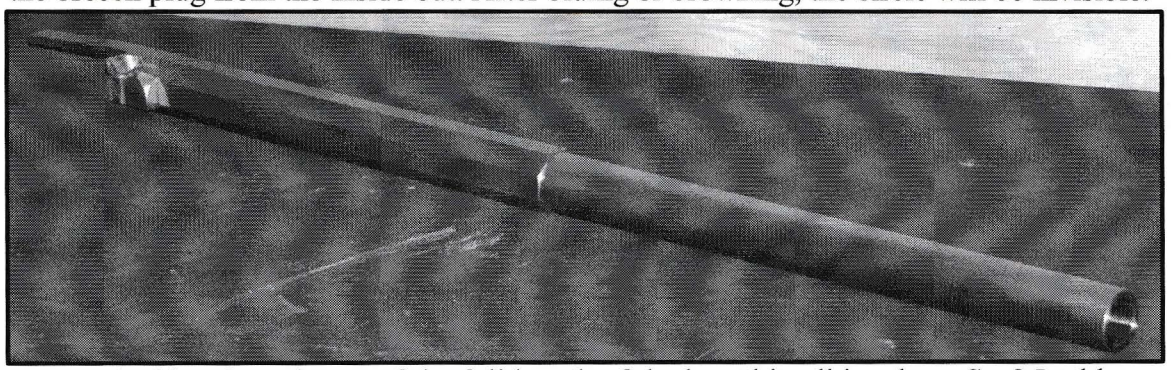


This is the view of the interface between the three parts from the other side. Note that the near-top oblique flat of the barrel extends back onto the tang of the standing breech. The tang was intentionally left a bit wide. It can either be trimmed down to

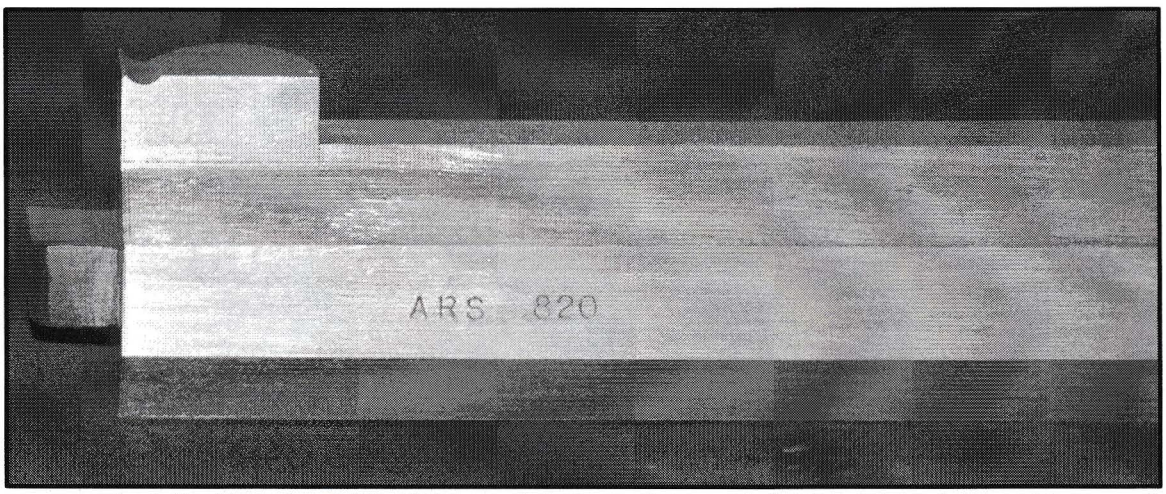
remove this oblique flat from the side, or it can be left full width and the top of the tang can be filed to match the contour of the stock in this area. The choice is up to whoever builds the barrel into a rifle. My personal inclination is to leave the tang wide up front and taper it to the rear, then blend the top of the tang to match the stock contour.



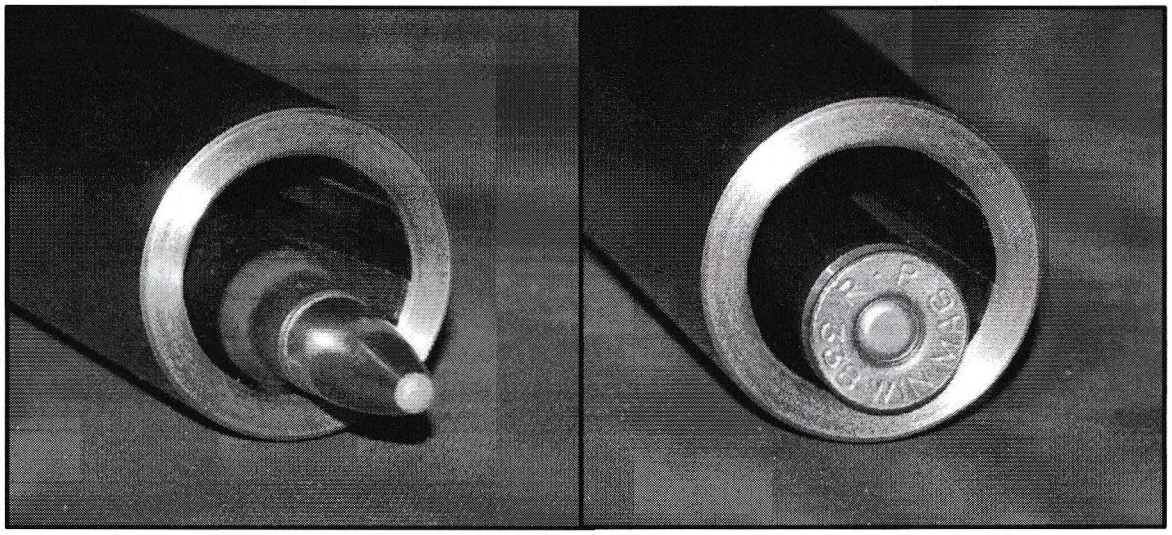
This is yet another view of the same parts. If you look carefully at all of these photos, you can see that file strokes made from different directions catch the light of the flash at different angles. If you've never done metal shaping like this, the file strokes can give you a clue as to how I go about it. Incidentally, in case you were wondering, the circle on the side of the breech plug is the surface of a plug. The flash-hole is drilled through the side of the breech plug to connect the nipple with the interior of the bore. The hole is tapped and plugged with a custom-made screw. The screw is soldered into place. The solder serves two purposes: it ensures that the plug can't back out and it also fills the space between the male and female threads– an important step in preventing corrosion of the breech plug from the inside out. After bluing or browning, the circle will be invisible.



And here's a picture of the full length of the barrel in all its glory. See? I told you I wasn't a professional photographer…



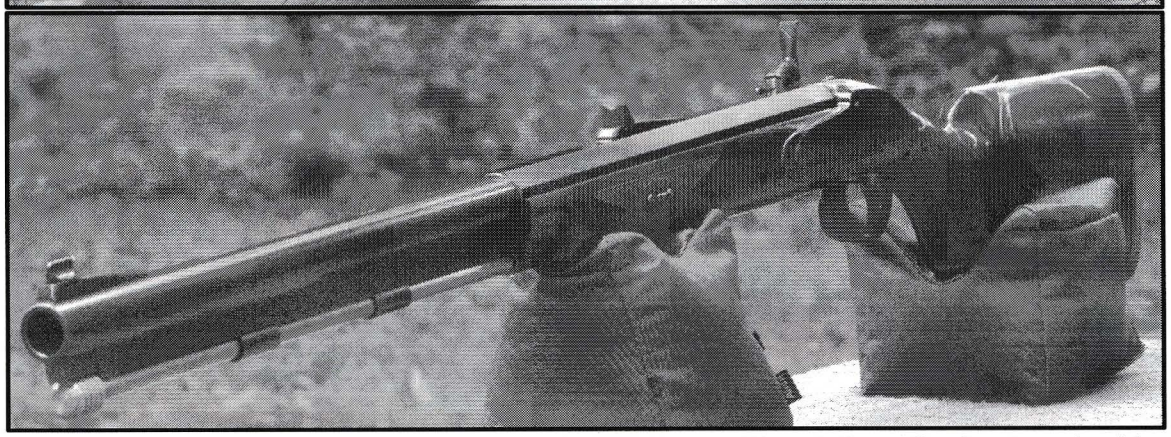
And finally, when all of the work is complete *and the barrel has passed its proof-firing test*, it gets my stamp of approval. The letters "ARS" stand for Appalachian Rifle Shop and ".820" is the measurement of the bore across the lands.



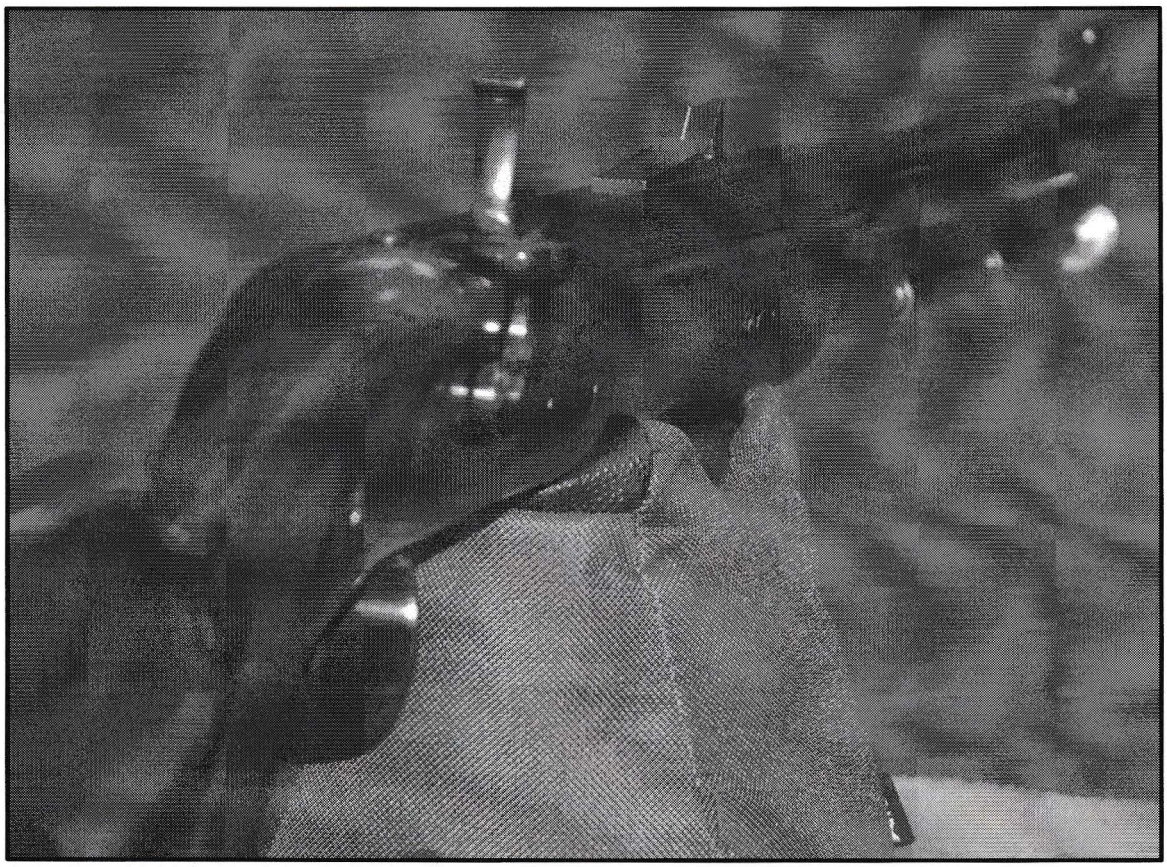
And here are a couple pictures just for fun. This is a .338 Winchester Magnum cartridge stretching its legs and relaxing inside the spacious 8-bore barrel, with plenty of headroom to spare. An 8-bore is a serious rifle…

Steel Helix

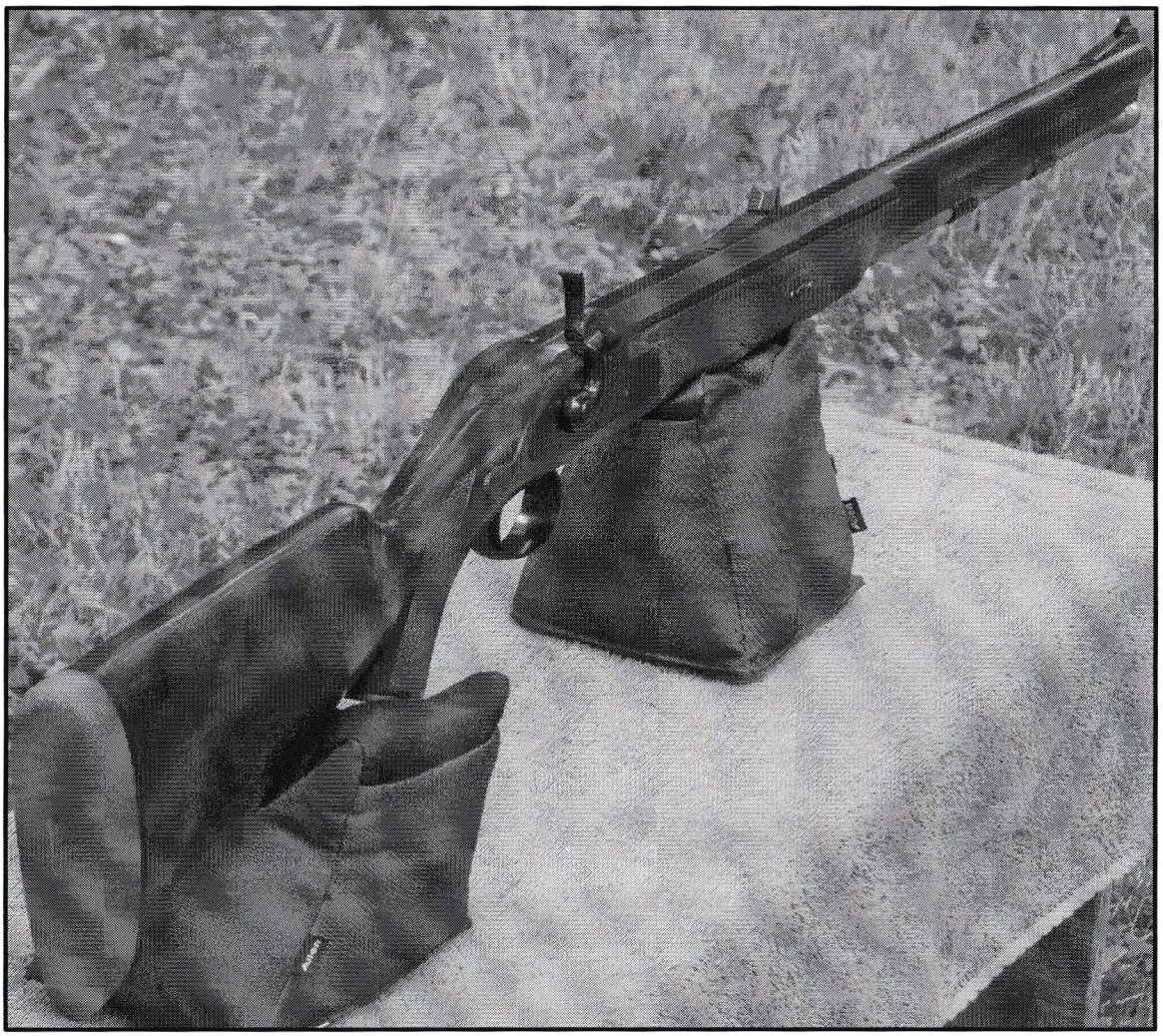
Below are a few pictures of a 69 caliber rifle that I built for myself. With the exception of the nipple, front sight blade and recoil pad, I made every single component (and I do mean, literally, *every* component) of this rifle myself from scratch. It was just a collection of bars and plates of raw steel and a plank of wood when I began work on it. In an effort to save you some head-scratching, I'll go ahead and tell you that this rifle was not crafted in any particular identifiable style– it is a hybrid design. I took the elements that I feel a muzzleloader built for the field should have from both the British sporting rifle and the American longrifle and combined them while raising the heel of the stock to provide the straight-line recoil that makes shooting the big boomers much more pleasant. The sight ramps are a necessary, non-traditional addition to elevate the sights to coincide with the shooter's line-of-sight in conjunction with the straightened stock. I know that my choice of design will offend some traditionalists, but, from a purely practical standpoint, this is a much better design for the large-bores than the standard, traditional muzzleloader stock architecture. This rifle was not built as homage to the riflesmiths of yore. This rifle was built to hunt.



These two pictures show the basic oblique profile of the rifle from each side. Look closely at the bottom photo. Do you see the little bug that decided to take a rest on top of the stock's comb? Did I mention that I'm not a professional photographer?



The idea with this photo was to showcase the express sights. The rear sight showed up quite nicely, but the front sight is just kind of a blur.



This is one of my favorite pictures of this rifle. Not only does the angle show off its curves nicely, but even better (and very surprisingly), the *whole rifle* is in focus from butt to muzzle! Maybe I'm not such a bad photographer after all… or maybe I just got very lucky (the smart money is on the latter option).

Now this is, without a doubt, my absolute favorite picture of this rifle. Why? Because it's posing with the very first critter it ever put on the ground, that's why. I wanted to make sure that I got at least one deer with the rifle that season. So, having already shot the one buck I was allowed during the regular firearms season the week before this photo was taken, I took the .69 out on antlerless day. I caught this doe sneaking down the mountain a bit after sunset at a range of 125 yards. Actually, it was more than a bit after sunset… there were only a couple minutes of shooting light left on a cloudy evening and it almost certainly would have been too dark to shoot with open sights if there hadn't been a skiff of snow on the ground. The deer was uphill and quartering slightly towards me. You can see the exit hole high up at the back of the ribcage. The entrance was a little lower and farther forward on the opposite side. No, the shot placement was definitely not ideal, but I did get the back of both lungs… barely. In my humble opinion, punching a hole through both of a deer's lungs from the kneeling position with an open-sighted muzzleloader in rapidly failing light at a range of 125 yards (the front sight bead looks as big as the deer's whole chest at that distance) isn't too shabby… and the one shot got the job done. I was pretty proud of my 100% hand-made rifle that evening.

This is the runner-up for the title of "My Favorite Picture of the .69". Care to guess why? If you guessed that it's because this is a photo of the first *buck* it ever put on the ground, then you have guessed correctly. Unfortunately, there is no tale of bravely battling adverse shooting conditions with this one. I shot him from the kneeling position too, but the range was a mere 80 yards and there was plenty of shooting light. My shot placement was considerably better as a result… got this one right through the heart. The rifle is capable of this level of accuracy all day, every day when I hold up my end of the bargain. If you're looking for the exit hole (which is on this side), it's right behind and slightly above the elbow. All you can really see is a little tuft of fur sticking up and a bit of blood trailing along his side from the wound. Don't ask me how you can punch a ¾" hole through a critter's chest with a 470 grain round ball and cause so little visible damage, because I don't know. But it does happen occasionally. Usually, however, that nearly one-inch hole is wide open and leaves a very good blood trail. That reliable blood trail is one of the main reasons that I love large-bore muzzleloaders so dearly.

BIBLIOGRAPHY

Moltrecht, Karl Hans. *Machine Shop Practice: Volume 1 & 2.* 2nd Edition. New York: Industrial Press, Inc., 1981.

Morris, George M. *The Starrett Book for Student Machinists.* 17th Edition. Athol: The L. S. Starrett Company, 1998.

O'Brien, J. J. & O'Brien, M. W. *How to Run a Lathe.* 42nd Edition. Bradley: Lindsay Publications, Inc., 1993.

Acker, Steve. *The Gunsmith Machinist.* Traverse City: Village Press, Inc., 2006.

Harvey, James A. *Machine Shop Trade Secrets: A Guide to Manufacturing Machine Shop Practices.* Garden Grove: ProShop Publishing, 2004.

Bryson, William E. *Heat Treatment, Selection, and Application of Tool Steels.* 2nd Edition. Cincinnati: Hanser Gardner Publications, 2005.

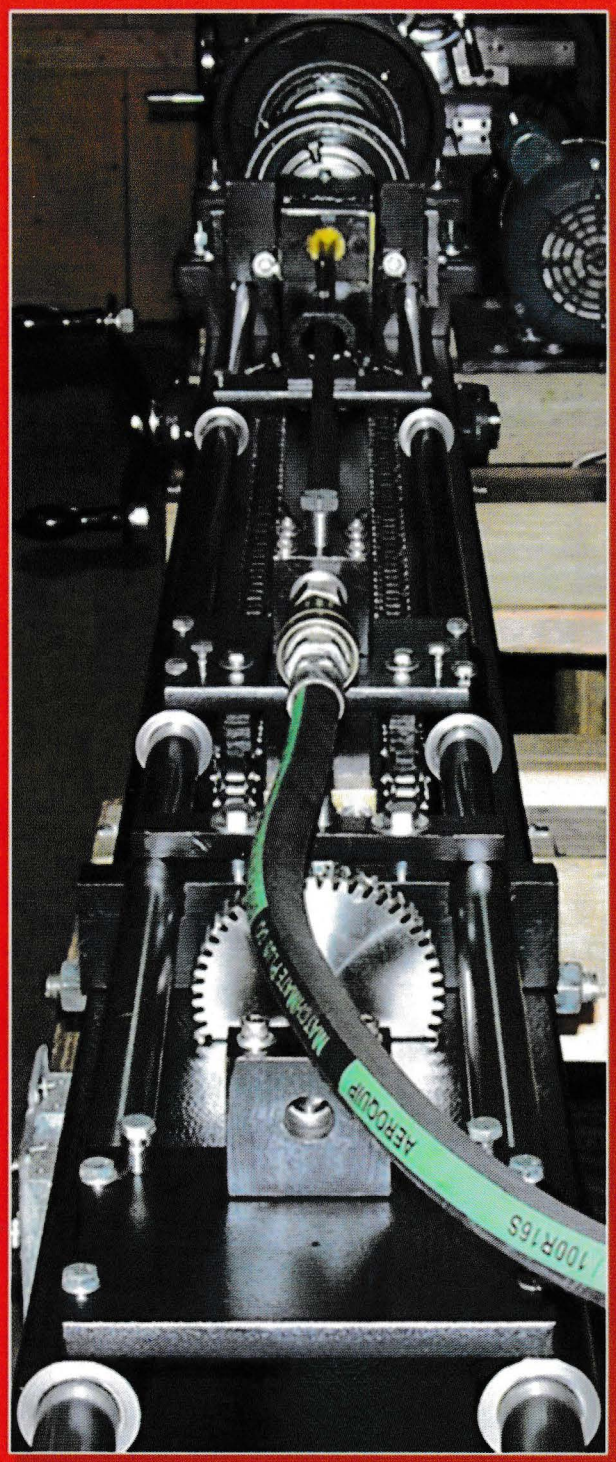
Machinery Magazine. *Making Rifle Barrels*. Bradley: Lindsay Publications, Inc., 2002.

LaBounty, Clifford F. *Rifling Machines and Methods*. Maple Falls: LaBounty Precision Reboring, Inc., 2011.

Wagner, Mark D. *Hand Rifling a Muzzle Loading Rifle Barrel at Home.* City unknown: Mark D. Wagner, 1996.

Lautard, Guy. *Bill Webb's Rifle Barrel Making Machine.* [DVD] West Vancouver: Barefoot Video Productions, 1995.

Dunlap, Robert. *How to Heat Treat Carbon Steels & Case Hardening Metal Parts Course.* [DVD] Napa: The American Gunsmithing Institute, 2007.



ISBN 978-0-615-86282-8
90000>
9 780615 862828

Steel Helix is the complete guide to the art of making rifle barrels from solid bars of steel. All aspects of the craft are thoroughly covered. From the fabrication of a machine and tooling capable of drilling, reaming and rifling to the machining know-how needed to put the tools to good use, this book has it all. *Steel Helix* puts the answers to every question you have ever asked about rifle barrels (as well as questions you never thought to ask) right at your fingertips. You are about to discover the secret tips and tricks of the trade, written by a riflesmith whose knowledge, skills and techniques have been honed by practical application on the range and in the field. The topics covered include:

- The three most common methods of rifling barrels and the limitations and advantages of each.
- Choosing between the available options for rotating a rifling cutter box to cut helical grooves in the barrel.
- Designing and fabricating a machine for deep-hole drilling, reaming and rifling.
- Designing and fabricating the cutting tools and tooling accessories needed to machine a solid bar of steel into a rifle barrel.
- Measuring the groove-circle diameter to manufacturing tolerances.
- Proof-firing the completed barrel.

Plus, an entire chapter detailing the chemical composition and mechanical properties of the most commonly used alloys of steel for rifle barrels.